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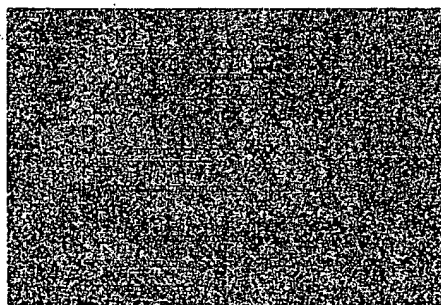
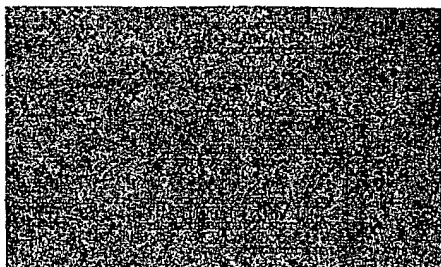
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(54) Title: DISPLACEMENT SANDWICH IMMUNO-PCR



(57) Abstract: The present invention is directed to labeling antibodies with DNA in a convenient kit format for the purpose of producing and utilizing nucleic acid detection immunoassays. The process comprises treating a reporter antibody with a chemically activated strand of DNA, which serves as a template for any DNA amplification system. The reporter antibody-DNA conjugate is used to form a complex with corresponding antigen. The complex can be detected by the production of multiple copies of the DNA template. The kit may also provide an activated DNA sequence to label a capture antibody. The DNA conjugated to the capture antibody is modified to contain a high affinity binding ligand for the purpose of coating a solid support. The coated solid support functions to capture the immune complex containing reporter antibody in a sandwich assay format. The DNA sequence of the capture antibody may also have properties providing for the detachment of the complex from the solid support.

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DISPLACEMENT SANDWICH IMMUNO-PCR**RELATED APPLICATIONS**

This application claims the benefit of priority to U.S. Application No. 60/423173, filed November 1, 2002, the entire contents of which are incorporated herein by reference.

10

FIELD OF THE INVENTION

This invention relates to methods for generating a signal in response to an analyte in present in a sample. Specifically, the invention relates to methods that employ detection by signal amplification of a nucleic acid marker and kits for performing the same. This invention also relates to a methods for labeling antibodies or other proteins with a nucleic acid, especially DNA; methods for purifying an antibodies and analytes; and methods for screening antibodies for diagnostic and therapeutic applications.

BACKGROUND OF THE INVENTION

One typical immunoassay is known as Enzyme Linked Immunosorbent Assay (ELISA). The antigen to be detected is removed from solution by non-specific adsorption to a solid surface, such as the inside of a microtiter plate well. After washing to remove excess antigen and blocking the remaining sites on the plate, the immobilized antigen is contacted with a primary antibody to form an immune complex on the solid support. Excess antibody can be removed by washing the plate. The primary antibody is detected via an enzyme, which can be directly conjugated to the primary antibody (direct ELISA) or to a second anti-antibody, which is subsequently contacted with the plate (indirect ELISA). The enzyme activity associated with the solid surface is proportional

5 to the amount of bound antigen present and can be measured, for example, by using a chromogenic substrate for the enzyme.

Immuno-PCR is similar to indirect ELISA, but uses a DNA sequence in place of an enzyme as the detection molecule (*see, e.g., Sano et al., Science, 1992, 258:120-22*). Sano *et al.*, demonstrated the efficacy of this method with a bovine serum albumin (BSA) antigen and anti-BSA primary antibody. Biotinylated plasmid DNA was coupled to the primary antibody via protein A-avidin. Amplification of the antigen-associated DNA by 30 cycles of polymerase chain reaction (PCR) permitted detection by staining with ethidium bromide following gel electrophoresis. The authors reported an enhanced detection sensitivity of approximately five orders of magnitude when compared to ELISA detection. Theoretically, a DNA label may be detected with extraordinary sensitivity (potentially down to a single copy) when amplified by PCR or any other exponential nucleic acid amplification technique. However, the sequential addition of each assay component requires extensive washing to sufficiently reduce non-specifically bound material.

20 Immuno-PCR can also be performed in a sandwich immunoassay format. A typical sandwich immunoassay employs two antibodies recognizing the antigen to be detected. A "capture" antibody is used to coat the surface of a solid support, such as a microtiter well, bead or particle. A "reporter" antibody is labeled with a detection molecule, such as a radioactive isotope, a fluorophore or an enzyme. In some cases the same antibody can be used for both capture and reporter. Typically, the antigen is first contacted with either the reporter antibody in solution or with the capture antibody on the solid support, followed by addition of the remaining antibody. The resulting specific immune complex is bound to the surface of the solid support and consists of the antigen

5 combined with two antibodies. Excess antigen and antibodies are removed by repeatedly washing the support. It is important to maintain the integrity of the immobilized immune complex during washing steps to maximize the signal strength while enhancing the removal of the unbound reporter antibody, thereby minimizing background. Following the washes, the bound reporter antibody is measured via the detection molecule as an
10 indication of the amount of antigen present.

The reporter antibody may be labeled directly by covalent modification of the antibody or indirectly through the binding of a second antibody or protein possessing a detectable label. Indirect attachment may be accomplished, for example, by labeling the reporter antibody with biotin and attaching the detection molecule to avidin. When the
15 detection system is sufficiently sensitive, the assay's lower limit will usually be determined by the degree of background produced by nonspecific binding of unbound reporter antibody.

Examples of sandwich immuno-PCR have also been reported in the literature (*see, e.g., Joerger et al., Clin Chem, 1995, 41:1371-77; Hendrickson et al., Nucleic Acids*
20 *Res, 1995, 23:522-529*). Detection limits for the sandwich Immuno-PCR assay format exceed those of conventional enzyme immunoassay. However, stringent washing, for example using detergent solution, is required to remove non-specifically bound DNA-labeled reporter antibodies.

The sandwich format of Immuno-PCR has also been used to demonstrate the
25 detection of multiple antigens ("multiplexing") (*see e.g., U.S. Pat. No. 5,985,548*). DNA labels of different length were each coupled to reporter antibodies recognizing distinct antigens using a 5' N-hydroxysuccinimide ester (NHS). The reporter antibody-DNA conjugates bound to a solid support coated with the various antigens. The multiple DNA

5 labels were detected simultaneously in the assay based on the sizes of the respective PCR amplification products, which had been designed to allow resolution from each other by gel electrophoresis.

Immuno-PCR offers a real improvement in sensitivity over present immunoassays, but is plagued by significant opportunities for generating background.

10 Background can be generated from nonspecific binding of any component, including the reporter antibody-DNA conjugate, the chimeric protein, or other secondary labeling component. Since single molecules of nucleic acid can be detected by PCR, failure to remove all of the nonspecifically bound template DNA molecules results in significant background and interferes with the ability to detect minute quantities of analyte.

15 Stringent, numerous or prolonged washes to reduce non-specific have been used to reduce background, but can result in reduced signal due to elution or dissociation of antigen/antibody complexes. Furthermore, Immuno-PCR is limited by the well-known non-linearity of PCR, which can frustrate attempts to assess the proportionate amounts of analyte present. These practical difficulties have prevented Immuno-PCR techniques

20 from gaining widespread acceptance and utility in the field.

A variety of methods have been suggested to reduce background in both standard immunoassays and Immuno-PCR methods. Ishikawa *et al.* (U.S. Pat. No. 5,888,834) has proposed the technique of immune complex transfer immunoassay, in which a sandwich immune complex is released from the capturing support and re-captured onto a fresh

25 surface. Non-specifically bound reporter components are left behind on the initial solid support. Nucleic acid hybridization assay sensitivity has also been improved by chemically eluting hybridized DNA from a solid support, leaving behind nonspecifically bound reporter DNA probe (*see Morrissey, et al., Anal Biochem* 1989, 181:345-359).

5 Target DNA was hybridized with dA-tailed capture probe and a labeled reporter probe.
Id. The complex was captured onto paramagnetic beads coated with oligo dT. *Id.* After
washing, the complex was released by eluting with a solution of guanidinium thiocyanate
and recaptured on a fresh support coated with poly dT. *Id.* Complexes have also been
released by the use of homopolymers, such as 200-400 by poly (rU), in combination with
10 washing in tetraalkylammonium salts (Collins *et al.*, US Patent No. 5,702,896).

Conceptually, Immuno-PCR has extraordinary theoretical sensitivity. The
technique, however, has not been exploited commercially due to the problem of
nonspecifically bound template DNA label, which obscures the true analyte signal. This
leads to the generation of false positive results and irreproducibility when attempting to
15 detect analytes present at low levels. Some investigators have concluded that immuno-
PCR is no more sensitive than ELISA in detecting IgG due to nonspecific binding
(McKie, *et al.*, *J. Immunol. Meth.*, 2002, 261:167175). The remarkable sensitivity
achieved by Sano *et al.* was demonstrated with a pure system using a cumbersome,
multi-step format, impractical for medical applications.

20 There is a need in the field of diagnostics and biosciences for a robust assay to
detect analytes present at vanishingly low levels or concentrations. This need will be
more keenly felt following the sequencing and analysis of the human genome. This
massive sequencing effort has resulted in the discovery of previously unrecognized
proteins which must be analyzed and characterized. Many of these proteins may be
25 present in amounts undetectable by current technology. The promise of Immuno-PCR to
provide highly sensitive methods for analyte detection has only been partially fulfilled.
Thus, there is a need to provide methods for immuno-PCR that have high sensitivity and
low background.

5

SUMMARY OF THE INVENTION

The invention relates to a process by which a capture antibody for a sandwich immunoassay is labeled with a specific double-stranded DNA molecule where the strand complementary to that attached to the capture antibody is modified with a high affinity ligand. Use of the ligand allows the complementary DNA strand to be attached to a solid support. The capture antibody/double-stranded DNA is then immobilized onto a solid phase comprising the corresponding high affinity ligand binding protein with the nucleic acid bridge linking the capture antibody to the solid phase. In preferred embodiments, a biotin/avidin binding pair is used, but other combinations of ligands and ligand-binders may also be employed. The solid phase may serve as a medium to capture antigen or antigen-reporter antibody immune complexes. The DNA strand may be imparted with properties allowing for the release of the immune complex from the capture medium to enhance detection sensitivity.

Although the instant invention is described herein by the exemplary use of DNA molecules as a bridge, displacer nucleic acids, and marker nucleic acids, in other embodiments nucleic acids other than DNA may be used, such as RNA or peptide nucleic acid (PNA), for one strand, both strands, or portions of one or both strands.

Diagnostic kits for performing such methods may be constructed to include a first container containing the capture antibody linked to a solid support with a nucleic acid bridge; a second container having a conjugate of the same or a different antibody and a marker DNA molecule; and a third container comprising a displacer nucleic acid. The diagnostic kit may also include notification of a FDA approved use and instructions therefor. One skilled in the art will readily recognize that antibodies other than those

5 described in the present invention can readily be incorporated into one of the established kit formats that are well known in the art.

This invention also relates to the process of labeling antibodies (or other proteins) with a DNA molecule of predetermined sequence. The DNA molecule can be subsequently detected with great sensitivity by PCR or any nucleic acid amplification
10 technique. Alternatively, the DNA molecule can be used to bridge the antibody or protein to a solid support. The DNA molecule may be attached directly to the antibody by first chemically activating the DNA, and then allowing the DNA molecule to bind to the antibody. A ligand binding protein may also be labeled with chemically-activated DNA, and then allowed to form a complex with the reporter antibody derivatized with
15 the corresponding ligand for the binding protein. Thus, either the reporter antibody, the capture antibody, or another protein may be attached to a DNA molecule via a direct covalent attachment.

Kits for performing such methods may be constructed to include a container having disposed therein a nucleic acid of predetermined sequence activated to be ready
20 to bind to a selected protein.

In one aspect, the invention consists of a kit for performing nucleic acid detection immunoassays comprising activated DNA molecules for labeling reporter and/or capture antibodies where the reporter antibody is to be labeled with a DNA marker strand and the capture antibody is to be labeled with a strand of a nucleic acid bridge. The kit further
25 comprises strands complimentary to the above-mentioned DNA molecules where the DNA complimentary in whole or in part to the above-mentioned DNA strand from the nucleic acid bridge is biotinylated, and a displacer strand that is complementary in whole or in part to the above-mentioned DNA strand from the nucleic acid bridge but is not

5 biotinylated. The kit may further comprise amplification primer(s), avidinylated
paramagnetic micro particles, binding and wash buffers, PCR reagents, and a dye for
detecting the amplification product, such as SYBR Green.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1: Figure 1A depicts a DNA sequence, attached to antibody, and hybridized to
10 the sequence anchored to the solid support via a 22 base hybridized region. The
displacer molecule hybridizes to anchor sequence at the solid support end via a 7 base
GC-rich footing and proceeds to displace the capture sequence along the next 20 bases,
leaving a AT hybrid at the antibody attachment end, which is unstable. Figure 1B
depicts an experiment where, in place of a capture antibody, alkaline phosphatase is
15 conjugated to a nucleic acid molecule and then bridged to a solid support. Figure 1C
depicts a first capture, followed by a displacement, followed by a recapture.

Figure 2: Background signal obtained by the displacement of the immune complex
from the paramagnetic microparticles.

Figure 3: Stability of Capture/Anchor Hybrid. Figure 3 shows that the capture/anchor
20 hybrid is stable under the salt conditions of the buffer used. The antibody/biotinylated
DNA conjugate remains bound to the well, as well as controls.

Figure 4: PNA Displacement and Salt Concentration. Figure 4 shows the effect of PNA
displacement on the bound antibody/biotinylated DNA conjugate. At low ionic strength,
PNA displacement is very effective, removing the antibody within a few minutes. It is
25 not as effective at high salt.

5 **Figure 5: DNA Displacement and Salt Concentration.** Figure 5 shows displacement by DNA. It is very effective at high salt, and ineffective in the absence of salt.

Figure 6: Figure 6 shows the result of a real-time PCR experiment. Figure 6A shows the real-time fluorescence signal obtained from a standard dilution series of anti-PSA rMAb-DNA conjugates. Figure 6B shows the threshold cycle as a function of the initial
10 number of rMAb-DNA molecules from (A).

DETAILED DESCRIPTION OF THE INVENTION

Definitions

The term “**analyte**,” as used herein, refers to any substance that can be detected in an assay, and which may be present in a sample. The analyte can be, without
15 limitation, any substance and preferably comprises a substance for which there exists a naturally occurring antibody or for which an antibody can be prepared. The analyte may, for example, be a protein, a polypeptide, a hapten, a carbohydrate, a lipid, a cell or any other of a wide variety of biological or non-biological molecules, complexes or combinations thereof. In preferred embodiments of the invention, analytes do not
20 contain nucleic acids.

The term “**non-nucleic acid analyte**” refers generally to an analyte that does not contain a nucleic acid that will interfere with immuno-PCR detection methods of the invention. Non-nucleic acid analytes of the invention do not solely consist of a nucleic acid molecules and typically, the non-nucleic acid analyte does not contain nucleic acids.
25 In preferred embodiments, the analyte may comprise a peptide, a protein, a carbohydrate, a lipid, a cell or any antigenic material. Analytes of the invention may comprise a nucleic acid component, but the binding of the analyte to be detected is not dependent on

- 5 complementary hybridization between any nucleic acid sequence in the analyte and a nucleic acid sequence in the receptor provided by the invention.

The term “sample” as used herein refers to an aliquot of material, frequently an aqueous solution or an aqueous suspension derived from biological material. Samples to be assayed for the presence of an analyte by the methods of the present invention

10 include, for example, cells, tissues, homogenates, lysates, extracts, and purified or partially purified proteins and other biological molecules and mixtures thereof.

Nonlimiting examples of samples typically used in the methods of the invention include human and animal body fluids such as whole blood, serum, plasma, cerebrospinal fluid, sputum, bronchial washing, bronchial aspirates, urine, lymph fluids and various external

15 secretions of the respiratory, intestinal and genitourinary tracts, tears, saliva, milk, white blood cells, myelomas and the like; biological fluids such as cell culture supernatants; tissue specimens which may or may not be fixed; and cell specimens which may or may not be fixed. The samples used in the methods of the present invention will vary based on the assay format and the nature of the tissues, cells, extracts or other materials,

20 especially biological materials, to be assayed. Methods for preparing protein extracts from cells or samples are well known in the art and can be readily adapted in order to obtain a sample that is compatible with the methods of the invention.

The term “contacting” as used herein refers generally to providing access of one component, reagent, analyte or sample to another. For example, contacting can involve

25 mixing a solution comprising a non-nucleic acid receptor with a sample. The solution comprising one component, reagent, analyte or sample may also comprise another component or reagent, such as dimethyl sulfoxide (DMSO) or a detergent, which facilitates mixing, interaction, uptake, or other physical or chemical phenomenon

5 advantageous to the contact between components, reagents, analytes and/or samples. In one embodiment of the invention, contacting involves adding a solution comprising a non-nucleic acid receptor to a sample utilizing a delivery apparatus, such as a pipette-based device or syringe-based device.

 The terms “non-nucleic acid receptor” or “receptor” as used herein refer to a
10 non-nucleic acid molecule that is capable of specifically binding another molecule. In one embodiment, the receptor is an antibody. In a preferred aspect of this embodiment, the receptor is a reporter antibody. In other embodiments of the invention, receptors can include, without limitation: biological receptor molecules, such as the insulin receptor; ligands for receptors, such as insulin; and other biological molecules that have affinity
15 for another molecule, such as biotin and avidin. The receptors of the present invention need not comprise an entire naturally occurring molecule but may only consist of a portion, fragment or subunit of a naturally occurring molecule, as for example the Fab fragment of an antibody. Receptors may be generated by any method known in the art. For example, antibodies may be found in a serum, prepared from a hybridoma tissue
20 culture supernatant or ascites fluid, or may be derived from a recombinant expression system, as will be well known in the art. Fragments, portions or subunits of *e.g.*, an antibody or other receptor, may be generated by chemical, enzymatic or other means, yielding for example, well-known (*e.g.*, Fab, Fab’) or novel molecules. The present invention also contemplates that receptors can include recombinant, chimeric and hybrid
25 molecules, such as humanized and primatized antibodies, and other non-naturally occurring antibody forms. Those skilled in the art will recognized that the non-limiting examples given above describing various forms of antibodies can also be extended to

5 other receptors such that recombinant, chimeric, hybrid, truncated etc., forms of non-antibody receptors can be used in the methods of the present invention.

"**Polyclonal antibodies**" are heterogeneous populations of antibody molecules derived from the sera of animals immunized with an antigen, or an antigenic functional derivative thereof. For the production of polyclonal antibodies, host animals such as
10 rabbits, mice and goats, may be immunized by injection with an antigen or hapten-carrier conjugate optionally supplemented with adjuvants.

"**Monoclonal antibodies,**" which are homogeneous populations of antibodies to a particular antigen, may be obtained by any technique that provides for the production of antibody molecules by continuous cell lines in culture. These include, but are not
15 limited to the hybridoma technique of Köhler and Milstein, *Nature*, 256:495-7 (1975); and U.S. Patent No. 4,376,110), the human B-cell hybridoma technique (Kosbor, *et al.*, *Immunology Today*, 4:72 (1983); Cote, *et al.*, *Proc. Natl. Acad. Sci. USA*, 80:2026-30 (1983)), and the EBV-hybridoma technique (Cole, *et al.*, in *Monoclonal Antibodies And Cancer Therapy*, Alan R. Liss, Inc., New York, pp. 77-96 (1985)). Such antibodies may
20 be of any immunoglobulin class including IgG, IgM, IgE, IgA, IgD and any subclass thereof. The hybridoma producing the mAb of this invention may be cultivated *in vitro* or *in vivo*. Production of high titers of mAbs *in vivo* makes this a presently preferred method of production.

In addition, techniques developed for the production of "**chimeric antibodies**"
25 (Morrison, *et al.*, *Proc. Natl. Acad. Sci.*, 81:6851-6855 (1984); Takeda, *et al.*, *Nature*, 314:452-54 (1985)) by splicing the genes from a mouse antibody molecule of appropriate antigen specificity together with genes from a human antibody molecule of appropriate biological activity can be used. A chimeric antibody is a molecule in which

- 5 different portions are derived from different animal species, such as those having a variable region derived from a murine mAb and a human immunoglobulin constant region.

Alternatively, techniques described for the production of single chain antibodies (U.S. Patent No. 4,946,778; Bird, *Science* 242:423-26 (1988); Huston, *et al.*, *Proc. Natl. Acad. Sci. USA*, 85:5879-83 (1988); and Ward, *et al.*, *Nature*, 334:544-46 (1989)) can be adapted to produce gene-single chain antibodies. Single chain antibodies are typically formed by linking the heavy and light chain fragments of the Fv region via an amino acid bridge, resulting in a single chain polypeptide.

- Antibody fragments that recognize specific epitopes may be generated by known techniques. For example, such fragments include but are not limited to: the F(ab')₂ fragments that can be produced by pepsin digestion of the antibody molecule and the Fab fragments that can be generated by reducing the disulfide bridges of the F(ab')₂ fragments. Alternatively, Fab expression libraries may be constructed (Huse, *et al.*, *Science*, 246:1275-81 (1989)) to allow rapid and easy identification of monoclonal Fab fragments with the desired specificity.

- By the terms “specifically binding” and “specific binding” as used herein is meant that an antibody or other molecule, especially a receptor of the invention, binds to a target such as an antigen, ligand or analyte, with greater affinity than it binds to other molecules under the specified conditions of the present invention. Antibodies or antibody fragments, as known in the art, are polypeptide molecules that contain regions that can bind other molecules, such as antigens. In various embodiments of the invention, “specifically binding” may mean that an antibody or other biological molecule, binds to a target molecule with at least about a 10⁶-fold greater affinity,

5 preferably at least about a 10^7 -fold greater affinity, more preferably at least about a 10^8 -fold greater affinity, and most preferably at least about a 10^9 -fold greater affinity than it binds molecules unrelated to the target molecule. Typically, specific binding refers to affinities in the range of about 10^6 -fold to about 10^9 -fold greater than non-specific binding. In some embodiments, specific binding may be characterized by affinities
10 greater than 10^9 -fold over non-specific binding.

The terms "polynucleotide" and "nucleic acid (molecule)" are used interchangeably to refer to polymeric forms of nucleotides of any length. The polynucleotides may contain deoxyribonucleotides, ribonucleotides and/or their analogs. Nucleotides may have any three-dimensional structure, and may perform any function,
15 known or unknown. The term "polynucleotide" includes single-, double-stranded and triple helical molecules. "Oligonucleotide" refers to polynucleotides of between 5 and about 100 nucleotides of single- or double-stranded nucleic acid, typically DNA. Oligonucleotides are also known as oligomers or oligos and may be isolated from genes, or chemically synthesized by methods known in the art. A "primer" refers to an
20 oligonucleotide, usually single-stranded, that provides a 3'-hydroxyl end for the initiation of enzyme-mediated nucleic acid synthesis. The following are non-limiting embodiments of polynucleotides: a gene or gene fragment, exons, introns, mRNA, tRNA, rRNA, ribozymes, cDNA, recombinant polynucleotides, branched polynucleotides, plasmids, vectors, isolated DNA of any sequence, isolated RNA of any
25 sequence, nucleic acid probes and primers. A nucleic acid molecule may also comprise modified nucleic acid molecules, such as methylated nucleic acid molecules and nucleic acid molecule analogs. Analogs of purines and pyrimidines are known in the art, and include, but are not limited to, aziridinycytosine, 4-acetylcytosine, 5-fluorouracil, 5-

5 bromouracil, 5-carboxymethylaminomethyl-2-thiouracil, 5-carboxymethyl-
aminomethyluracil, inosine, N6-isopentenyladenine, 1-methyladenine, 1-
methylpseudouracil, 1-methylguanine, 1-methylinosine, 2,2-dimethylguanine, 2-
methyladenine, 2-methylguanine, 3-methylcytosine, 5-methylcytosine, pseudouracil, 5-
10 pentylnyluracil and 2,6-diaminopurine. The use of uracil as a substitute for thymine in a
deoxyribonucleic acid is also considered an analogous form of pyrimidine.

The term “nucleic acid marker” refers to a nucleic acid molecule that will
produce a detection product of a predicted size or other selected characteristic when used
with appropriately designed oligonucleotide primers in a nucleic acid amplification
reaction, such as a PCR reaction. Skilled artisans will be familiar with the design of
15 suitable oligonucleotide primers for PCR and programs are available over the Internet to
facilitate this aspect of the invention (*see*, for example, the [http site:
bibiserv.techfak.uni-bielefeld.de/genefisher](http://bibiserv.techfak.uni-bielefeld.de/genefisher)). A nucleic acid marker may be linear or
circular. In preferred embodiments, the nucleic acid marker will comprise a
predetermined, linear nucleic acid sequence with binding sites for selected primers
20 located at or near each end. In a circular DNA nucleic acid molecule, the primers will be
internal rather than at an end, and a single primer may be used, *e.g.* for Rolling Circle
Amplification. Amplified DNA may be detected using any available method, including,
but not limited to techniques such as real time PCR, SYBR Green staining, or ethidium
bromide staining. In other embodiments of the invention, the binding sites for the
25 amplification primers flank an undefined DNA sequence of defined length or which
comprises another identifiable characteristic, such as a detectable sequence, in addition
to undefined sequences. In some embodiments, the nucleic acid marker are
distinguished by the size or mass of the amplified sequences; thus, the DNA sequence

5 between the primers need not be defined as to the exact sequence, just as to the number of bases. Alternatively, the size and/or sequence of the entire nucleic acid marker need not be defined as long as a binding site for a molecular beacon (*see, infra*) is supplied. In further embodiments, the DNA sequence located between the primer binding sites comprises a "characteristic identification sequence" capable of being detected during the
10 PCR reaction. Fluorescent signal generation may, for example, be sequence-specific (Molecular Beacons, Taq Man, fluorogenic primers, such as the LUX primers (Invitrogen (Carlsbad, CA.)) or mass dependent (SYBR Green, Ethidium Bromide). The examples provided are not meant to be an exhaustive list of possible nucleic acid detection schemes as those skilled in the art will be aware of alternative markers suitable
15 for use in the methods of the present invention.

The term "characteristic identification sequence" refers to a nucleic acid sequence that can be specifically detected by virtue of hybridization to oligonucleotide or other nucleic acid that has been labeled with a detectable marker such as a radioisotope, a dye (such as a fluorescent dye), or other species that will be known in the art. In
20 preferred embodiments, the characteristic identification sequence is capable of binding a "molecular beacon" probe. The term "molecular beacon" refers to oligonucleotides such as those sold by Operon Technologies (Alameda, CA) and Synthetic Genetics (San Diego, CA). (*See also*, Tyagi and Kramer, *Nat Biotechnol*, 1996, 14:303-308; and Tyagi *et al.*, *Nat Biotechnol*, 2000, 18:1191-96.). As noted herein, a signal can be generated
25 using a variety of techniques and reagents.

The term "analyte-dependent reporter complex" refers to the complex formed by a receptor that has been labeled with a nucleic acid marker and bound to a non-nucleic

5 acid analyte. In a preferred embodiment, the complex is specific, stable and has a high degree of specificity.

The term "solid support" refers any solid phase that can be used to immobilize *e.g.*, an analyte, an antibody or a complex. Suitable solid supports will be well known in the art and include the walls of wells of a reaction tray, such as a microtiter plate, the
10 walls of test tubes, polystyrene beads, paramagnetic or non-magnetic beads, nitrocellulose membranes, nylon membranes, microparticles such as latex particles, and sheep (or other animal) red blood cells. Typical materials for solid supports include, but are not limited to, polyvinyl chloride (PVC), polystyrene, cellulose, nylon, latex and derivatives thereof. Further, the solid support may be coated, derivatized or otherwise
15 modified to promote adhesion of the desired molecules (*e.g.*, analytes) and/or to deter non-specific binding or other undesired interactions. The choice of a specific "solid phase" is usually not critical and can be selected by one skilled in the art depending on the assay employed. Thus, latex particles, microparticles, paramagnetic or non-magnetic beads, membranes, plastic tubes, walls of microtiter wells, glass or silicon chips, and red
20 blood cells are all suitable sold supports. Conveniently, the solid support can be selected to accommodate various detection methods. For example, 96 or 384 well plates can be used for assays that will be automated, for example by robotic workstations, and/or those that will be detected using, for example, a plate reader. For methods of the present invention that may involve an autoradiographic or chemiluminescent detection step
25 utilizing a film-based visualization, the solid support may be a thin membrane, such as a nitrocellulose or nylon membrane. According to one embodiment of the invention in which sandwich immunoassays are performed, the walls of the wells of a reaction tray are typically employed. In alternative embodiments of the instant invention,

5 paramagnetic beads may be used as a solid support. Suitable methods for immobilizing molecules on solid phases include ionic, hydrophobic, covalent interactions and the like, and combinations thereof. However, the method of immobilization is not typically important, and may involve uncharacterized adsorption mechanisms. A "solid support" as used herein, may thus refer to any material which is insoluble, or can be made
10 insoluble by a subsequent reaction. The solid support can be chosen for its intrinsic ability to attract and immobilize a capture reagent. Alternatively, the solid phase can retain an additional receptor which has the ability to attract and immobilize a capture reagent. The additional receptor may include a substance that is oppositely charged with respect to either the capture reagent itself or to a charged substance conjugated to the
15 capture reagent. In yet another embodiment of the invention, an additional receptor molecule can be any specific binding member which is immobilized upon (attached to) the solid phase and which has the ability to immobilize a capture reagent through a specific binding reaction. The additional receptor molecule enables indirect immobilization of the capture reagent to a solid phase before or during the performance
20 of the assay. The solid phase thus can be a plastic, derivatized plastic, paramagnetic or non-magnetic metal, glass or silicon surface of a test tube, microtiter well, sheet, bead, microparticle, chip, or other configurations known to those of ordinary skill in the art.

The term "**nucleic acid bridge**" refers to a partially or wholly double-stranded nucleic acid moiety that functions to connect non-nucleic acid receptors of the invention
25 to a solid support. The nucleic acid bridge typically consists of two nucleic acid molecules, one of which is attached to a solid support of the invention, while the other is attached to the non-nucleic acid receptor. These two nucleic acid molecules hybridize to each other by their complementary regions, thereby connecting the non-nucleic acid

5 receptor to the solid support. In some embodiments of the invention, DNA is used as the nucleic acid bridge. In other embodiments, nucleic acids other than DNA may be used, such as RNA or peptide nucleic acid (PNA), for one strand, both strands, or portions of one or both strands. In preferred embodiments of the present invention, the double-stranded portion of the nucleic acid bridge is completely complementary. However, in
10 other embodiments, the double-stranded portion of the nucleic acid bridge is substantially complementary. By the term “**substantially complementary**” is meant that two nucleic acid sequences have at least about 80% or more nucleic acid complementarity, preferably at least about 90% or more nucleic acid complementarity, more preferably at least about 95% or more nucleic acid complementarity, and most
15 preferably at least about 99% or more nucleic acid complementarity. Complementarity describes the ability of nucleotide bases in one nucleic acid strand to pair with an opposing base in another nucleic acid strand. As is well known in the art, adenine bases in DNA pair with thymidine, while cytosine and guanine form a complementary pair. Complementarity is measured by dividing the number of complementary bases pairs in
20 two nucleic acid sequences by the total number of bases and multiplying the product by 100. Thus, exact complements display 100% complementarity along their entire length, while sequences that are less similar and have, *e.g.*, mismatched bases, have a lower degree of complementarity. In typical embodiments of the invention, the complementarity is sufficient to maintain double-stranded binding of the nucleic acid
25 bridge prior to the use of the displacer nucleic acid, under the conditions employed.

In preferred embodiments, the strand of the nucleic acid bridge attached to the non-nucleic acid receptor is attached covalently by a linking group at its 5' end. In preferred embodiments, the strand of the nucleic acid bridge attached to the solid support

5 is attached thereto by a biotin/avidin bridge wherein the biotin is covalently attached to the 5' end of this nucleic acid bridge molecule, and the biotin binds to a biotin-receptor, such as avidin, attached to the solid support. In preferred embodiments, the nucleic acid bridge attached to the solid support is covalently attached to the solid support by a linking group at the 5' end of the nucleic acid molecule. In further preferred
10 embodiments, the sequence of the nucleic acid molecule attached to the solid support is selected from the group consisting of SEQ ID NO:1, SEQ ID NO:4, and SEQ ID NO:7. In other embodiments, the partially complementary strand that is attached to a capture non-nucleic acid receptor (or reporter enzyme such as alkaline phosphatase) is selected from the group consisting of SEQ ID NO:2, and SEQ ID NO:5. In additional
15 embodiments, the non-nucleic acid receptor is an antibody. These embodiments are exemplary only, and other nucleic acid sequences may be used, as will be apparent to one of skill in the art. Furthermore, other means may be used to attach the nucleic acid bridge to the solid support.

The term “**detecting**” as used herein refers to any method of verifying the
20 presence of a given molecule. The techniques used to accomplish this may include, but are not limited to, PCR, sequencing, PCR sequencing, molecular beacon technology, hybridization, and hybridization followed by PCR. Examples of reagents which might be used for detection include, but are not limited to, radiolabeled probes, enzymatic labeled probes (horseradish peroxidase, alkaline phosphatase), and affinity labeled
25 probes (biotin, avidin, or streptavidin).

The term “**eluted**” or “**eluting**” refers to extracting, dissociating or removing a bound or adsorbed material from an adsorbent by means of a molecule, buffer, or solvent in a controlled fashion. In one embodiment, the elution uses a selected molecule to

5 disrupt, dissociate or destabilize the link to the solid support without significantly
changing the buffer or other conditions. In one aspect of this embodiment, the selected
molecule competes with the bound or adsorbed material for binding to the adsorbent. In
a preferred embodiment, the selected molecule is a nucleic acid molecule that comprises
a region of sequence complementarity to the nucleic acid strand of a double-stranded
10 nucleic acid bridge attached to the solid support. In still other embodiments, the elution
can be accomplished using restriction enzymes or endonucleases which are well known
in the art. Examples of common restriction enzymes include, but are not limited to as
Eco RI, Hind III and Nco I.

 The term “displacer nucleic acid” refers to a nucleic acid of predetermined
15 sequence that is used to elute an analyte-dependent reporter complex from a solid
support. In preferred embodiments of the invention, the sequence is selected from the
group consisting of SEQ ID NO:3, and SEQ ID NO:6.

 In one embodiment of the invention, the displacer nucleic acid is a DNA
molecule. In other embodiments, the displacer nucleic acid is an RNA molecule. In
20 further embodiments, the displacer nucleic acid is a PNA molecule. In still other
embodiments, the displacer nucleic acid is a phosphorothioate molecule. These
embodiments are not meant to be limiting, and other embodiments are possible.

 The term “nucleic acid replication composition” refers to compositions that
provide a means of replicating a nucleic acid sequence. Typically, the composition will
25 consist of such components as buffer, salts, co-factors, enzymes, primers and/or other
reagents required for replicating a nucleic acid. Replication can be by any means
available for replicating the target nucleic acid sequence and the skilled artisan will
recognize that a wide variety of methods are available. In preferred embodiments of the

5 invention, the means of replicating DNA is the polymerase chain reaction (*see, e.g.*, Sambrook and Russell, Molecular Cloning, a Laboratory Manual, 3rd ed., 2001). In other nonlimiting embodiments of the invention, amplification is performed by the techniques of (1) isothermal amplification of DNA (*see e.g.*, PCT International Application No. WO 00/41524); (2) Single Temperature Strand Displacement Amplification (SDA) (*see e.g.*,
10 U.S. Pat. No. 5,270,184); (3) Transcription Mediated Amplification (TMA) (U.S. Pat. No. 5,766,849); or Ligase Chain Reaction (LCR) (*see e.g.*, Wu & Wallace, 1989, *Genomics* 4:560).

The term “**hapten**” as used herein, refers to a small proteinaceous or non-protein antigenic determinant which is capable of being recognized by an antibody. Typically,
15 haptens do not elicit antibody formation in an animal unless part of a larger species. For example, small peptide haptens are frequently coupled to a carrier protein such as keyhole limpet hemocyanin in order to generate an anti-hapten antibody response.

“**Antigens**” are macromolecules capable of generating an antibody response in an animal and being recognized by the resulting antibody. Both antigens and haptens comprise at
20 least one antigenic determinant or “**epitope**,” which is the region of the antigen or hapten which binds to the antibody. Typically, the epitope on a hapten is the entire molecule.

“**Peptide**” generally refers to a short chain of amino acids linked by peptide bonds. Typically peptides comprise amino acid chains of about 2-100, more typically about 4-50, and most commonly about 6-20 amino acids. “**Polypeptide**” generally refers
25 to individual straight or branched chain sequences of amino acids that are typically longer than peptides. “**Polypeptides**” usually comprise at least about 100 to 1000 amino acids in length, more typically at least about 150 to 600 amino acids, and frequently at least about 200 to about 500 amino acids. “**Proteins**” include single polypeptides as

- 5 well as complexes of multiple polypeptide chains, which may be the same or different. Multiple chains in a protein may be characterized by secondary, tertiary and quaternary structure as well as the primary amino acid sequence structure, may be held together, for example, by disulfide bonds, and may include post-synthetic modifications such as, without limitation, glycosylation, phosphorylation, truncations or other processing.
- 10 Antibodies such as IgG proteins, for example, are typically comprised of four polypeptide chains (*i.e.*, two heavy and two light chains) that are held together by disulfide bonds. Furthermore, proteins may include additional components such associated metals (*e.g.*, iron, copper and sulfur), or other moieties. The definitions of peptides, polypeptides and proteins includes, without limitation, biologically active and
- 15 inactive forms; denatured and native forms; as well as variant, modified, truncated, hybrid, and chimeric forms thereof. The peptides, polypeptides and proteins of the present invention may be derived from any source or by any method, including, but not limited to extraction from naturally occurring tissues or other materials; recombinant production in host organisms such as bacteria, fungi, plant, insect or animal cells; and
- 20 chemical synthesis using methods that will be well known to the skilled artisan.

- As used herein, the term “distinguishable” refers to an ability to distinguish experimentally between the two different markers or species. In embodiments in which an assay is used to detect multiple analytes, none of the multiple DNA marker molecules will consist of sequences identical in both length and sequence. Two markers may
- 25 comprise the same core sequence, but the markers will be distinguishable on the basis of size and/or different sequences. In preferred embodiments, the PCR products will be different in length. In other embodiments, the markers will have sequences which bind

- 5 to different sequence specific probes. These embodiments are not limiting, and other embodiments can be envisioned being used with the invention.

The term “conjugate” as used herein refers to two molecules which have been covalently attached, or otherwise linked together. In one embodiment, a nucleic acid conjugate is generated by covalently linking the nucleic acid to a polypeptide. In a
10 preferred embodiment of the invention, a non-nucleic acid receptor, as used herein, and a polypeptide are covalently attached via a linking group to form a conjugate.

A “kit” for detecting the presence of a selected analyte in a sample by the methods of the invention comprises at least one container means having disposed therein the capture antibody linked to the solid support of the kit by a nucleic acid bridge. The
15 kit may also comprise a container means having disposed therein the reporter antibody, or a container means having disposed therein the displacer nucleic acid. The kit may further comprise other containers comprising one or more of the following: wash reagents, reagents capable of amplifying the bound nucleic acid probe reagents, and agents capable of detecting the presence of bound nucleic acid probe after amplification.
20 Preferably, the kit further comprises instructions for use. The kit, if intended for diagnostic use, may also include notification of a FDA approved use and instructions therefor.

Specifically, a compartmentalized kit includes any kit in which reagents are contained in separate containers. Such containers include small glass containers, plastic
25 containers or strips of plastic or paper. Such containers allow the efficient transfer of reagents from one compartment to another compartment such that the samples and reagents are not cross-contaminated and the agents or solutions of each container can be added in a quantitative fashion from one compartment to another. Such containers will

5 include a container which will accept the test sample, a container which contains the probe or primers used in the assay, containers which contain wash reagents (such as phosphate buffered saline, Tris-buffers, and the like), and containers which contain the reagents used to detect the marker nucleic acid, amplified product, or the like. One skilled in the art will readily recognize that the antibodies labeled with nucleic acid
10 molecules described in the present invention can readily be incorporated into one of the established kit formats that are well known in the art.

A kit for coupling DNA to an antibody or other protein by the method of the invention comprises at least one container means having disposed therein the lyophilized activated DNA. The kit may further comprise other containers comprising one or more
15 of the following: wash reagents, and agents capable of detecting the presence of attached nucleic acid probe after the reaction. Preferably, the kit further comprises instructions for use. One skilled in the art will readily recognize that the activated nucleic acids described in the present invention can readily be incorporated into one of the established kit formats that are well known in the art.

20 **Displacement Sandwich Immuno-PCR**

The present invention provides methods for detecting analytes of interest in various fields, including clinical diagnostics and biological sciences. The Displacement Sandwich Immuno-PCR method of the present uses a reporter antibody directly labeled with 1 or 2 molecules of oligonucleotide using protein crosslinking chemistry. The 1 or
25 2 oligonucleotides attached to the reporter antibody may be single- or double-stranded. The invention further relates to the process of detecting an antigen (Ag) in a sample using one or more labeled antibodies. The invention also relates to a process by which a

- 5 capture antibody or a reporter antibody, or other protein, is labeled with a specific DNA sequence.

According to one method of the invention, a non-nucleic acid analyte present in a sample is detected by:

- (i) contacting a sample comprising a non-nucleic acid analyte with a reporter conjugate,
10 wherein the reporter conjugate comprises a first receptor capable of specifically binding the analyte, and a nucleic acid marker;
- (ii) allowing the binding of the analyte to the reporter conjugate, thereby forming an analyte-dependent reporter complex;
- (iii) contacting the analyte-dependent reporter complex with a second receptor for the
15 analyte, wherein the second receptor is attached to a solid support via a nucleic acid bridge of predetermined sequence;
- (iv) allowing the binding of the second reporter to the analyte-dependent reporter complex, thereby forming an analyte-dependent reporter/second reporter complex attached to the solid support;
- 20 (v) eluting the analyte-dependent reporter/second receptor complex from the solid support with a displacer nucleic acid; and
- (vi) specifically detecting the presence of the nucleic acid marker in the eluted analyte-dependent reporter/second receptor complex, wherein the detection of nucleic acid marker indicates the presence of the analyte in the sample.

- 25 One aspect of this method is a process commonly known as Immuno-PCR, whereby an antibody (Ab), particularly a monoclonal antibody (MAb), is labeled with a specific sequence of nucleic acid which is typically DNA, for the purpose of detecting the formation of an immune complex by monitoring the enzymatic amplification of, for

5 example, the DNA. The immune complex may be formed with a single DNA-labeled reporter monoclonal antibody (rMAb), or in a sandwich immunoassay format in concert with a capture monoclonal antibody (cMAb). Polyclonal antibodies may also be employed when appropriate. The nucleic acid label may be detected with extraordinary sensitivity, down to a single copy of the molecule, when subjected to amplification by
10 the Polymerase Chain Reaction (PCR), or any other exponential nucleic acid amplification technique (*e.g.*, (1) Tabor *et al.* (WO 00/41524); (2) Single Temperature Strand Displacement Amplification (SDA) (U.S. Pat. No. 5,270,184); (3) Transcription Mediated Amplification (TMA) (U.S. Patent No. 5,766,849; or Ligase Chain Reaction (LCR) (Wu, D.Y. & R.B. Wallace, 1989, Genomics 4, 560).

15 Typically, the nucleic amplification will be accomplished by PCR using a polymerase. Suitable polymerases are well known in the art and may include without limitation, DNA polymerases, RNA polymerases, transcriptases, and Q-beta polymerases. The skilled artisan will recognize that the choice of polymerase will depend on what type of nucleic acid is amplified. According to one embodiment of the
20 invention, a replication composition comprising reagents and primers for conducting a polymerase chain reaction is used for nucleic acid amplification. The composition will generally comprise the buffer, nucleotides, salts, enzyme and other components required for performing PCR or another amplification procedure.

Methods of the present invention can also be performed using real time PCR, in
25 which a specific sequence of, *e.g.*, DNA is quantified by monitoring its rate of amplification during thermocycling in the presence of Taq polymerase, appropriate primers and nucleotide triphosphates. (For a brief discussion of real time PCR, *see* Walker, 2002, Sci 296:557-58.)

- 5 Conveniently, the methods of the present invention can be used to detect multiple analytes present in a single sample (*i.e.*, multiplexing). For example, a multiplicity of different non-nucleic acid analytes present in a single sample can be simultaneously detecting, by performing the steps of:
- 10 (i) contacting a sample comprising a multiplicity of different non-nucleic acid analytes with a multiplicity of reporter conjugates, where each reporter conjugate comprises a first receptor capable of specifically binding one of the multiplicity of non-nucleic acid analytes in the sample, and a nucleic acid marker, and where each reporter conjugate binds specifically to a different analyte and comprises a nucleic acid that is distinguishable from the other nucleic acids in the multiplicity of reporter conjugates;
- 15 (ii) allowing the binding of the multiplicity of non-nucleic acid analytes in the sample to the multiplicity of receptor conjugates, thereby forming a multiplicity of analyte-dependent reporter complexes;
- 20 (iii) contacting the multiplicity of analyte-dependent reporter complexes with a multiplicity of second receptors, wherein the multiplicity of second receptors is collectively capable of binding to the multiplicity of analytes in the sample, and wherein the second receptors are attached to a solid support via a nucleic acid bridge of predetermined sequence;
- 25 (iv) allowing the binding of the second reporters to the analyte-dependent reporter complexes, thereby forming a multiplicity of analyte-dependent reporter/second reporter complexes attached to the solid support;
- (v) eluting the multiplicity of analyte-dependent reporter/second receptor complexes from the solid support with at least one displacer nucleic acid; and

5 (vi) specifically detecting the presence the nucleic acid markers in the eluted multiplicity of analyte-dependent reporter/second receptor complexes by visualizing the replicated nucleic acid marker by ethidium bromide staining., wherein the detection of each distinguishable nucleic acid marker indicates the presence of the corresponding analyte in the sample.

10 A typical assay according to this method might employ four or more different receptors, such as antibodies, each specific for a distinct analyte. Where antibodies are used as the receptors, the analytes are antigens or haptens, such as serum components. It may be desirable, for example, to simultaneously measure two or more such serum components as hormones, enzymes and disease markers in the same reaction. Thus, one
15 could perform an assay designed to measure risk for diseases by determining the serum concentration of, *e.g.*, cholesterol, insulin, PSA, CA125 and other disease related species in blood. According to this aspect of the invention, nucleic acid markers are designed such that each can be distinguished, for example, on the basis of size. Thus, for an assay of four analytes, the nucleic acid markers might be 50, 70, 90 and 110 nucleotides in
20 length, respectively. Following amplification, PCR products can be resolved and quantified using such techniques as gel electrophoresis and mass spectroscopy.

Another aspect of the invention relates to the screening of antibodies for diagnostic and therapeutic application. More specifically, the invention provides methods for labeling test antibodies with a specific sequence of nucleic acid. The
25 nucleic acid label may then be detected with great sensitivity by PCR or any nucleic acid amplification technique. A DNA label, for example, may be attached directly to the antibody using chemically activated DNA. Alternatively, a binding protein may be

- 5 labeled with chemically-activated DNA and contacted with a reporter antibody
derivatized with the corresponding ligand for the binding protein, to form a complex.

The present invention also provides methods for preparing DNA activated with a chemical crosslinking compound and storing the activated DNA in kit form.

- According to this method, an oligonucleotide (typically about 10-100 bases) to be
10 attached to an antibody, peptide, polypeptide or protein is synthesized to contain a 5'
amino linkage and is activated with excess suberate. The intermediate is quickly isolated
and added to a concentrated solution of, *e.g.*, monoclonal antibody (MAb).
Alternatively, activated oligonucleotide may be stored for future use. The
oligonucleotide-MAb conjugate can be purified by gel filtration and anion exchange
15 chromatography. A complimentary strand may be hybridized to the first (*e.g.*, oligo-
MAb conjugate), forming a double-strand DNA bridge for use in Displacement Sandwich
Immuno-PCR assays (described below). In the case of a capture antibody, the second
complimentary strand may be biotinylated with a commercial reagent at the 5' end and
used to coat paramagnetic particles or other material containing bound avidin. The solid
20 phase serves as a medium to capture antigen (Ag) or Ag-MAb immune complexes. A
DNA strand attached to the capture antibody may be imparted with properties allowing
for the release of the immune complex from the capture medium in order to enhance
detection sensitivity.

- Kits of the present invention for labeling proteins, polypeptides or peptides
25 typically comprise a container containing DNA molecules activated with disuccinimidyl
suberate. The DNA molecules can, for example, be a first strand of a nucleic acid bridge,
or a first strand of a marker DNA molecule. In one embodiment, the kits also contain
directions for labeling proteins, polypeptides or peptides using the kit.

5 The present invention also provides novel methods for detecting analytes using nucleic acid displacement. According to these methods, generally, a non-nucleic acid analyte present in a sample is contacted with a reporter conjugate. The reporter conjugate comprises: a first receptor capable of specifically binding the analyte; and a nucleic acid marker. The analyte is then allowed to bind to the reporter conjugate,
10 thereby forming an analyte-dependent reporter complex. The analyte-dependent reporter complex is then contacted with a second receptor for the analyte, wherein the second receptor is attached to a solid support via a nucleic acid bridge of predetermined sequence. Binding of the second reporter to the analyte-dependent reporter complex, forms an analyte-dependent reporter/second reporter complex attached to the solid
15 support, which can then be eluted, for example, using displacer nucleic acid. Finally, the presence of the nucleic acid marker can be detected as an indicator of the presence analyte in the sample.

 One application of this embodiment is in Displacement Sandwich Immuno-PCR assay (DSI-PCR). According to this embodiment, excess reporter antibody/DNA
20 conjugate is added in solution to antigen, forming a first immune complex. The complex is captured on a solid support coated with a second antibody via a double-stranded nucleic acid bridge. Extensive washing removes most of the excess reporter antibody (greater than 99%). In preferred embodiments, this analyte/reporter complex is then gently removed by the use of a displacer nucleic acid. The eluted DNA label associated
25 with the immune complex is amplified by PCR, and monitored continuously by the generation of a fluorescent signal. The use of real time PCR, where the rise in the concentration of nucleic acid copies is observed during the course of a PCR amplification reaction, allows the determination of the original number of marker DNA

5 sequences, and thereby the number of analyte molecules. This avoids the uncertainty in quantifying PCR products in reactions carried to completion. A single copy of either marker DNA or the corresponding reporter MAb conjugate can be statistically detected. The presence of ten copies is detected with certainty.

Performing the DSI-PCR assay in the absence of antigen/analyte and without the
10 elution step results in the "detection" of about 5000 copies of reporter MAb-DNA due to nonspecific binding. Further washing does not diminish this background. It has been noted that removal of excess reporter MAb-DNA by extensive washing under a given set of buffer conditions will always leave some reporter nonspecifically bound to the support. Additional washing steps under another set of conditions, such as elevated
15 temperature or ionic strength, would produce a fresh "bloom" of eluted background signal, demonstrating that the prior washing conditions had not been sufficient to remove all background signal.

The difficulty in eliminating nonspecifically bound reporter MAb-DNA suggested eluting or removing the antigen/immune complex (for example, PSA/anti-
20 PSA) from the solid support prior (e.g., avidin paramagnetic particle) to PCR amplification. One means to accomplish this was by interposing a 26 base pair double-stranded spacer arm containing restriction end nuclease sites between the capture MAb and the biotin used to link to the solid support. Complimentary 26-mer DNA molecules containing a 5' amino linkage were synthesized to contain nuclease sites for both Hind
25 III and Eco RI when hybridized. The amino function on one DNA strand was derivatized with biotin. The second strand was conjugated to capture MAb and then hybridized to the biotinylated strand. The double-stranded capture MAb conjugate was fully bound by immobilized avidin and released with both Hind III and, more efficiently,

5 with Eco RI digestion. A captured PSA immune complex was effectively cleaved from the solid support by Eco RI treatment 37° C for 15 min. These conditions, however, also eluted nonspecific reporter Mob-DNA. Sensitivity when using anti-PSA antibody improved to only 5,000,000 copies of PSA. Similar results were obtained with streptavidin- or avidin-coated microtiter plates.

10 The further reduction of background, and enhancement of assay sensitivity, requires the removal of the specific immune complex from the solid support by the use of a displacer nucleic acid as described in the instant invention. The MAb-Ag-MAB immune complex is released back into solution and transported to a fresh vessel. Nonspecifically bound or trapped reporter MAb is left behind on the solid support or the
15 walls of the original assay container. This has the effect of purifying the specific immune complex. If the release and transfer of the complex is efficient, signal intensity is maintained while background signal is reduced.

The sensitivity of the DSI-PCR assay has been enhanced in this invention by: (1) directly labeling the reporter MAb with a short synthetic strand of marker DNA; (2)
20 employing MAb sandwich pairs with affinity constants $> 10^{10}$; (3) reducing the input reporter MAb concentration 1000-fold (to circa 0.01 nM); (4) optimizing blocking and washing protocols; and (5) minimizing solid support surface area and capture MAb coating.

In the present invention, further improvements to the DSI-PCR sensitivity have
25 been accomplished by design of a linkage between the capture MAb and the immunoassay support allowing for the specific displacement of immune complex into solution using extremely mild elution conditions specifically tailored to the nucleic acid bridge used.

5 In one embodiment of the invention, a capture MAb is labeled with a strand of synthetic DNA (capture strand) through a 5' amino linkage. A synthetic DNA strand (anchor strand) containing 5' biotin and a complimentary 3' sequence is hybridized to the capture strand. The capture/anchor-DNA/DNA conjugate is used to coat the surface of avidin microtiter plates or paramagnetic microparticles or another suitable solid support. The capture MAb is subsequently displaced from the support by addition of excess displacer oligonucleotide containing sequences complimentary to both the 5' end of the anchor strand and the 3' end of the capture strand. The displacer hybridizes near the 5' end of the anchor stand and displaces the capture strand as that strand hybridizes near the 3' end of the capture strand. The capture DNA-DNA conjugate is released into solution as a function of the equilibrium and relative stability of the original versus newly hybridized anchor strand.

Displacement is accomplished without alteration in most solution conditions, including, without limitation, pH, temperature, or ionic strength, all of which have been shown to independently release nonspecifically bound reporter MAb-marker DNA conjugate back into solution. Displacer DNA removes the entire MAb-Ag-MAb immune complex and unbound MAb. Only the immune complex contains marker DNA recognized by PCR primers. The concomitant release of excess capture MAb affects neither signal nor background. The application of immune complex displacement to Immuno-PCR results in a 10-fold improvement in detection by background signal reduction. Detection sensitivities of a few hundred molecules of protein antigen (approximately five attograms) have been achieved.

Immuno-PCR, as described by Sano and Cantor, employs an antibody labeled with a biotinylated fragment of DNA via a chimeric protein bridge consisting of avidin

5 and protein A. The DNA label was amplified by the polymerase chain reaction and detected semi-quantitatively by gel electrophoresis followed by staining with ethidium bromide. *Id.* The multi-step complexity of the assay of Sano & Cantor required long incubation and wash cycles, in excess of the half-life of the primary immune complex, resulting in loss of signal and accuracy due to macromolecular dissociation. Although
10 more recent investigators have added improvements, temporal constraints, reagent complexity and DNA template contamination have inhibited a widespread application of this technology. For example, Watanabe and co-workers have embarked on a series of studies to optimize the DNA concentration and streptavidin concentrations for use in conjunction with specific antibodies (Sugawara, *et al.*, *Clin Chem. Act*, 299:45-54, 2000
15 (angiotensinogen), Saito *et al.*, *Clin Chem.*, 45:5:665-669, 1999 (tumor necrosis factor- α), and Furuya *et al.*, *J. Immunol. Methods*, 238:173-180, 2000 (interleukin-18)). Joerger *et al.* used DNA conjugated directly to antibodies specific for human thyroid-stimulating hormone and chorionic gonadotropin in preparation for developing an assay capable of detecting both antigens simultaneously (Joerger *et al.*, *Clin Chem* 41/9:1371-
20 1377, 1995). Subsequently, Hendrickson *et al.* demonstrated a multianalyte immunoassay for simultaneous detection of three analytes (hTSH, hCG and beta-Gal) using DNA-labeled antibodies (Hendrickson *et al.* *Nucl. Acids Res.* 14:6115-28, 1986) *see also*, U.S. Pat. No. 5,985,548)). Jablonski *et al.* also described techniques for directly attaching DNA molecules to protein molecules (Jablonski *et al.*, *Nucl. Acids Res.*
25 23/3:522-29, 1995). For further methods of conjugating DNA molecules to polypeptides, *see* Hermanson, *Bioconjugate Techniques*, pp 639-666, 1996, which is incorporated herein by reference, including any drawings, figures and tables.

- 5 According to another embodiment, the displacement methods of the present invention purification of antibodies, analytes and complexes thereof can be performed. One aspect of this embodiment comprises a method for reversibly binding an antibody/analyte complex to a solid support, the method comprising the steps of:
- 10 (i) providing an antibody/analyte complex, where the 5' end of a first nucleic acid is conjugated to the antibody, the analyte comprises an antigen recognized by the antibody, and the analyte is specifically bound to the antibody through the antigen combining site of the antibody;
- (ii) providing a solid support comprising a second nucleic acid, wherein the 5' end of the second nucleic acid is bound to the solid support, wherein the second nucleic acid is
- 15 substantially complementary to the first nucleic acid over its 3' terminus;
- (iii) binding the antibody/analyte complex to the solid support by means of a double-stranded nucleic acid bridge, wherein the nucleic acid bridge is formed by hybridization of the unbound ends of the first and second nucleic acids; and
- (iv) eluting the antibody/analyte complex from the solid support by means of a
- 20 displacer nucleic acid.

 As described above, methods for eluting the non-nucleic acid molecule typically utilize a displacer nucleic acid molecule under conditions that favor displacement of the nucleic acid bridge with the displacer nucleic acid, but reduce or eliminate elution of non-specifically bound species. In alternative embodiments, any

25 means of specifically eluting the non-nucleic acid molecule without contaminating non-specific species can be used. For example, an endonuclease, such as a restriction

5 enzyme can be used to digest the double-stranded bridge, thereby eluting the non-nucleic acid molecule.

In further embodiments of the invention, a method for labeling antibodies or ligand binding proteins directly with DNA and a means for performing nucleic acid detection immunoassays with real-time PCR in a kit format that will be robust in use are
10 provided. The format of the invention allows for the improved and practical application of an Immuno-PCR assay. The methods of the present invention reduce the problem of DNA-marker non-specific binding, which plagues all exponential nucleic acid amplification assays. The present invention also provides for accuracy and quantification by employing real-time PCR detection.

15 **Kit for Labeling Proteins with Nucleic Acid Molecules**

Another aspect of the present invention relates to methods for labeling antibody molecules. According to this aspect, a DNA reagent is provided that, when contacted in solution under appropriate conditions, forms a covalent linkage to, *e.g.* an antibody. The DNA reagent may be single- or double-stranded. If single-stranded, the DNA label may
20 be converted to a duplex by hybridization with a fully or partially complementary strand.

The DNA reagent is formed by the synthesis of a DNA sequence containing a primary amine functional group. The primary amine may be located anywhere on the DNA molecule, but in preferred embodiments, the amine is located at the 5' terminus of the DNA. The amine-containing DNA is contacted with an excess of amine-reactive
25 cross-linking agent under appropriate reaction conditions and the amine moiety on the DNA reacts with the cross-linking agent. The activated DNA is isolated by gel filtration chromatography under conditions that maintain residual cross-linking activity. The

5 DNA reagent is distributed in known quantities into appropriate vessels, quick-frozen and lyophilized to dryness. Antibody (in solution) added to the lyophilizate reacts with the unreacted end of the cross-linking agent to form a covalent conjugate to DNA. Excess hydrolyzed reagent may be removed, for example, by one or more passages through an ultra filter having an appropriate molecular weight cutoff to discriminate
10 antibody from DNA.

The invention further provides methods for labeling a ligand binding protein. A solution of binding protein is used to hydrate the lyophilized DNA reagent (prepared as described above). The unreacted portion of the cross-linking agent combines with specific amino acid residues within the protein structure to form a covalent attachment to
15 the DNA. The DNA-labeled binding protein may be contacted with antibody labeled with the corresponding ligand, resulting in a DNA-antibody conjugate.

A additional aspect of the present invention provides a method for performing the DSI-PCR assay using the DNA-antibody conjugation process. One such immunoassay according to this aspect of the invention utilizes a sandwich format, whereby an immune
20 complex is formed using two antibodies to different epitopes on the same antigen. One of the pair of antibodies (reporter) is labeled with marker DNA. The second antibody (capture) is immobilized on a solid surface to capture the immune complex formed by the reporter antibody and antigen. The antibody-antigen-antibody complex may be formed by combining all reactants simultaneously or sequentially. The immobilized
25 immune complex is separated from excess reporter antibody-DNA conjugate by washing, followed by selective elution, and the marker DNA is detected by PCR amplification.

5 The PCR reaction is initiated by the addition of the four different nucleoside triphosphates, an oligonucleotide primer pair for each template being amplified, a thermostable enzyme which catalyzes the polymerization of the nucleoside triphosphates from the end of the primer, and any other reagents required for the PCR reaction. Amplification of the DNA template strands is accomplished by successive heating and
10 cooling steps.

 The PCR reaction may be detected by common DNA quantification techniques, including gel electrophoresis, dot blot hybridization, and autoradiography. Preferably, PCR is monitored in real time using an automated thermocycler and fluorescence signal generation (*see, e.g.,* Walker, 2002, *Science* 296:557-58). Florescence signal generation
15 may, without limitation, be sequence-specific (Molecular Beacons, Taq Man, fluorogenic primers) or mass dependent (SYBR Green, Ethidium Bromide).

 PCR amplification and detection may be carried out on the immune complexes bound to the solid support, or on complexes dissolved back into solution. Advantageously, the release of bound immune complex from a capturing solid surface
20 enhances sensitivity by eliminating non-specifically bound DNA-reporter antibody conjugate.

 Another form of nucleic acid detection immunoassay uses an immunostaining format. A thin section of tissue fixed to a solid surface is contacted with antibody that has been labeled with a DNA marker. If antigen is present, an immune complex will
25 form on the tissue section. The sample is washed free to remove excess antibody-DNA reagent and individual cells maybe isolated by the technique of laser capture. Individual captured cells may then be lysed, causing the release and solubilization of antigen-

- 5 antibody complexes. The marker DNA label can be quantified during or after amplification.

In yet another aspect of the invention, antibodies raised against haptens may be screened for activity against a given antigen by labeling with a DNA marker through complex formation with a binding protein-DNA conjugate.

- 10 All U.S. patents and applications; foreign patents and applications; scientific articles; books; and publications mentioned herein are hereby incorporated by reference in their entirety, including any drawings, figures and tables, as though set forth in full.

- The present invention may be better understood by the following examples, which are intended only to illustrate the present invention and should in no way be
- 15 construed as limiting the subject invention.

5

EXAMPLES**Example 1: Activation of 5' Amino DNA.**

A 59 base marker DNA sequence:

5' NH₃-(C12)-TGCCTAGCGA TGACTAGCTG CTGATCGATA TTAGCTAGCA
10 TCAGCGATCG ATACGAGCA-3' (SEQ ID NO:13)

was synthesized to contain a single primary amine group at the 5' end via a 12-carbon spacer arm (Glen Research, Sterling, VA). The 5' amino-DNA (350 µg) was dissolved in 20 µl 10.05 M sodium phosphate buffer, pH 8.0. Disuccidimidyl suberate was dissolved in dry DMSO at a concentration of 12 mg/ml. A 40 µl aliquot was added
15 immediately to the DNA solution and mixed by gentle re-pipetting. After one minute at room temperature, the reaction mixture was loaded onto a 0.5 x 20 cm G-25 (fine) column equilibrated in 5 mM citric acid, adjusted to pH 5.4 with 0.1 M sodium hydroxide, and developed at a flow rate of 0.5 ml/min at room temperature. The first eluted peak was collected directly into an Centricon YM-10 Centrifugal Filter Device
20 (Millipore Corp., Bedford MA) embedded in ice. The suberate-activated template DNA was concentrated by centrifugation at 5000-x g for 30 minutes at 4 °C, to 200-300 µl. The DNA concentration was determined by absorbance at 260 nm. One A₂₆₀ unit (approximately 30 µl) was distributed into micro centrifuge tubes containing 5 µl of 10% mannitol, and immediately frozen in dry ice/acetone bath. The pellets were lyophilized
25 to dryness, sealed under dry argon and stored frozen.

The activity of the lyophilized activated DNA was assessed by reaction with a small amine-containing molecule. Glutathione at 50 mg/ml in 0.1 M sodium phosphate, pH 8.0 was reacted with a stoichiometric amount of N-ethylmaleimide (NEM). The pH

5 was re-adjusted to 8.0 with sodium hydroxide. One A₂₆₀ unit of suberate-activated DNA was dissolved in 10 µl of NEM-glutathione, then diluted 25-fold with water to 4.0 A₂₆₀ units/ml. Conjugation with NEM-glutathione resulted in a single slower migrating band on 15 % polyacrylamide TBE-urea gel electrophoresis compared to unmodified 5' amino DNA. Suberate activated DNA, purified and lyophilized under the described conditions,
10 typically exhibits nearly 100% conjugation to NEM-glutathione, indicating complete activation and maintenance of amine reactivity.

Example 2: Conjugation of Monoclonal Antibody to DNA.

One hundred microliters monoclonal antibody to PSA (1 mg/ml) (A45110136P from Biospecific, Emeryville, CA) was concentrated and exchanged into 0.1 M sodium
15 phosphate, 0.15 M sodium chloride, pH 8.25 by two passes through a Microcon YM-50 centrifugal filtration device at 10,000 x g in a microcentrifuge at room temperature. The final volume of 25 to 50 µl was collected by centrifugation into a microcentrifuge tube and added to a lyophilized pellet of activated marker DNA. The conjugation reaction was allowed to proceed for several hours at room temperature.

20 The degree of antibody labeling was assessed by SDS and native protein gel electrophoresis. The incorporation of one or more strands of DNA into an antibody structure increases both the molecular weight and negative charge density. Antibodies labeled with one or more strands of DNA appear as distinct slower migrating bands on 4% SDS gel electrophoresis, which correspond to the degree of incorporation. These
25 same conjugated molecules migrate faster than corresponding underivatized antibody on 4-12% native protein gel electrophoresis. The separation is more dramatic, but less well defined for higher order conjugates on native gels.

5 The extent of DNA conjugation was assessed by relative band densities for free and conjugated antibody, and varied from 50 to 100%, depending on the relative reactivity and exposure of lysine amine groups contained within the antibody structure. The degree of labeling was determined by the number and relative density of conjugate protein bands, and indicated a mixture of predominately single- and double- DNA labels
10 per antibody.

 Unreacted DNA was removed from the conjugate preparation by FPLC gel filtration chromatography employing a Superdex 200 HR 10/30 column (Amersham Pharmacia, Piscataway, NJ) equilibrated in phosphate-buffered saline. Unreacted antibody was removed by FPLC anion exchange chromatography using a Mono Q HR
15 5/5 column equilibrated in 20 mM Tris-Cl buffer, pH 8.0. and a 5%/min NaCl gradient to 1.0 M at 0.5 ml/min.

 The conjugated DNA was rendered double-stranded by hybridization to a complementary 59-mer oligonucleotide:

5' -TGCTCGTATC GATCGCTGAT GCTAGCTAAT ATCGATCAGC AGCTAGTCAT
20 CGCTACGCA-3' (SEQ ID NO:18)

 Excess complimentary DNA was removed by several passes through a Microcon YM- 100 centrifugal filter device.

Example 3: Labeling Monoclonal Antibody With Biotin.

 Capture MAb to PSA (A45120136P (Biospecific)) was labeled with biotin for
25 immobilization on avidin-coated solid supports. Capture MAb (1 mg/ml) was reacted with 7.5 and 15-fold molar excess sulfo-NHS-LC-biotin (Pierce, Rockford, Ill.) in 0.1 M sodium phosphate, pH 8.0, for 2-4 hours at room temperature. The reaction yielded 3.6

- 5 and 7.3 moles biotin/mole MAb, respectively, as determined by reaction with HABA. The biotinylated capture MAb was purified on a desalting column, and tested for immune reactivity to prostate specific antigen (PSA) by ELISA.

Example 4: Labeling 5' Amino DNA With Biotin.

- Oligonucleotides synthesized to contain a 5' amino (C12) linkage were
- 10 biotinylated by the addition of excess solid sulfo-NHS-LC-biotin to 1-5 mg/ml solution in 0.1 M sodium bicarbonate, pH 8.5. The reaction was allowed to proceed for 4 hours to overnight at room temperature. Biotinylated DNA was purified from the reaction mixture by HPLC using a C-18 reverse phase column eluted with a gradient of acetonitrile in water. Pure biotinylated oligonucleotides were dried by vacuum
- 15 centrifugation and stored frozen.

Example 5: Preparation Of Paramagnetic Micro Particles Coated With CmaB-Biotin.

- Bio-Mag Streptavidin paramagnetic particles (Polysciences, Warrington, PA) or SeraMag-Streptavidin (Seradyn, Ramsey, MN) (5 mg in 500 μ l) were placed in a 2 ml
- 20 screw cap vial. Particles were collected to the side of the vial under a magnetic field, and the supernatant discarded. Particles were washed twice by magnetic collection and resuspension in 2 ml Phosphate Buffered Saline containing 0.05% Tween-20. Particles were resuspended in 1 ml blocking solution (PBS containing 1% bovine serum albumin, 0.1 mg/ml salmon sperm DNA and 0.1% sodium azide) and transferred to a 50 ml
- 25 conical tube. To this, 24 ml of 10 nM biotinylated cMAb (labeled with biotin either directly, as in example 3, or via a double-stranded DNA bridge) in blocking solution was added, followed by an incubation for one hour under gentle agitation at room temperature. Particles were washed three times by magnetic collection and resuspension

5 in 25 ml PBS/Tween and once in PBS. The particles were resuspended in 2.5 ml blocking solution and stored at 4 °C.

Similarly, Reacti-Bind NeutrAvidin Polystyrene microtiter plates (Pierce, Rockford, IL.) were also coated with cMAb via a biotin label. The degree of coating on the supports was monitored by loss of biotinylated MAb from solution as measured by
10 bicinchoninic acid (Pierce BCA Protein Assay Reagent). Immobilized capture MAb was shown by protein gel electrophoresis to bind PSA and PSA reporter MAb-DNA complex.

Example 6: Sandwich Immuno-PCR Assay For Prostate Specific Antigen.

Eighty (80) µl of 12.5 pM rMAb-DNA conjugate from Example 1 in blocking
15 solution was added to each sample well in an iCycler plate (Bio-Rad, Hercules CA), followed by 20 µl of aserum sample or standard dilution series. The solution was gently mixed by repipetting. The plate was covered with sealer to prevent evaporation and incubated 2 hours at room temperature to form the first immune complex in solution

cMAb - biotin-coated magnetic microparticles (5 µl) were added and mixed by
20 gentle repipetting. The plate was covered with sealer and incubated for 30 min under gentle agitation to capture the PSA immune complex onto particle.

Particles were collected to the sides of the wells under a magnetic field and the supernatant was drawn off using a pipette fitted with filter tips. The particles were resuspended in 120 µl TKMT (10 mM Tris, pH 8.0 containing 50 mM KCl, 1.5 mM
25 MgCl₂, 0.05% Tween20) using filter tipped pipettes. This collection and resuspension of the particles was repeated an additional five times, increasing the volume of each

- 5 successive wash by 20 μ l. This ensured the removal of excess reporter MAb-DNA conjugate from the liquid meniscus on the walls of the well.

Capture of the PSA Immune Complex Onto Particles.

- The particles were resuspended in 50 μ l of PCR reaction (Platinum Quantitative PCR Super Mix, Invitrogen, Carlsbad, CA) containing SYBR green @ 1:30000
- 10 (Molecular Probes, Eugene, OR), 10 nM fluorescein, 0.2 μ M each primer, and 0.5 x TKMT. The plate was covered with optical quality sealing tape and gently tapped to dislodge bubbles at the bottom of the wells. PCR amplification was carried out automatically for 40 cycles of 95°C melt for 15 sec and 62°C extension for 1 minute in an iCycler Instrument. The fluorescence intensity was monitored in real time and a cycle
- 15 number was recorded for each sample that achieved a threshold level of signal. This threshold cycle number was then compared to values obtained for a standard dilution series of marker DNA. Assays of this format typically detected about 5000 molecules of PSA above background (signal in the absence of PSA). Figure 6 shows the results of a real-time PCR assay of marker DNA attached to rMAb for PSA.

20 Example 7: Displacement Immuno-PCR Assay for Prostate Specific Antigen.

Capturing antibody to PSA (Biospecific A45120136P) was conjugated to:

5' -NH₃ (C12) -TAGGACTTCAGACTGGGACGAT-3' (SEQ ID NO:2)

and hybridized to:

- 3' -ATCCTGAAGTCTGACCCTGCTAGCTCGAG- (C12)NH₃-5' -biotin (SEQ ID
- 25 NO:1)

- 5 The other set was resuspended in 25 μ l of 1 μ M displacer oligonucleotide of the sequence:

5' -GGACTTCAGA CTGGGACGAT CGAGCTC-3' (SEQ ID NO:3)

- dissolved in TKMT. The particles were collected by magnetic field and the supernatant
10 subjected to real-time PCR analysis using the same primers. The signal from each reaction was analyzed against a standard curve of rMAb-DNA conjugate.

The results shown in Figure 2 indicate a background reduction of approximately 10-fold by the displacement of the immune complex from the paramagnetic microparticles, resulting in a commensurate improvement in ultimate assay sensitivity.

15 **Example 8: Displacement Reactions.**

- Endonuclease Cleavage:** A dissociable linker connecting capture MAb to biotin was constructed using a 26 base pair double-stranded DNA containing restriction endonuclease sites (SEQ ID NO:17). The 26- base oligonucleotides, each containing a 5' amino linkage were synthesized to contain both Hind III and Eco RI restriction sites
20 when hybridized. The amino function on one DNA strand was derivatized with sulfo-NHS-LC-biotin. The second strand was conjugated to capture MAb against PSA followed by hybridization to the biotinylated complementary strand. The biotinylated capture MAb conjugate was fully bound by immobilized avidin (or streptavidin) and released by digestion with a restriction endonuclease. Both Hind III and Eco RI were
25 employed, with Eco RI digestion being more efficient. A captured PSA-reporter MAb immune complex was effectively cleaved from the paramagnetic support by Eco RI treatment at 37 °C for 15 min. These conditions, however, eluted nonspecific reporter MAb-DNA conjugate as well. Sensitivity of a sandwich Immuno-PCR assay (Example

- 5 6) improved marginally for the detection of PSA when the immune complex was displaced from the solid support by restriction cleavage of the DNA linker. Similar results were obtained with streptavidin- or avidin-coated microtiter plates.

5' CAGGTAGAAT TCCTAAGCTT CAGGCT (SEQ ID NO:17)

3' GTCCATCTTA AGGATTCGAA GTCCGA

10 Eco R1 Hind III

Displacement: Another means to reduce background during the final PCR reaction employed a dissociable double-strand DNA linker between the capture MAb and the biotin used to link to the solid support. Peptide nucleic acid (PNA) is known to form extremely tight hybrids with complimentary DNA and was used to displace a
15 hybridized DNA strand of the same sequence. The capture MAb was biotinylated via a linker arm composed of double-stranded DNA, which would dissociate in the presence of excess complimentary PNA.

Protein Nucleic Acid: Peptide nucleic acid (PNA) is known to form extremely tight hybrids with complimentary DNA and was used to displace a hybridized DNA
20 strand of the same sequence.

A 22 base DNA anchor sequence was synthesized with a 5' amino function and biotinylated. A 15 base DNA capture sequence, complimentary to the 3' end of the anchor sequence, was synthesized with a 5' amino function and conjugated to the capture MAb. Capture MAb conjugate was hybridized to biotinylated anchor sequence, leaving
25 a 7 base single-strand region at the 5' end of the anchor. Identical 18 base displacer sequences of PNA and DNA were synthesized to be complimentary to the 5' end of the anchor sequence. Hybridization of the displacer sequence to the 7 base open region on the anchor probe would "displace" the hybridized capture sequence, releasing the

5 immune complex, and thus template DNA, into solution. The biotinylated anchor sequence and hybridized displacer sequence, as well as surface bound reporter MAb-DNA, would remain with the avidin-coated support. The supernatant would be transferred to a new vessel for PCR amplification. This system is called capture/displacement (*see, e.g.*, Figure 1).

10 The capture sequence was also conjugated to alkaline phosphatase in order monitor and optimize the capture/displacement system by following enzyme activity. This arrangement of DNA sequences demonstrated the capture and release from avidin particles and microtiter wells. Surprisingly, it was found that the DNA displacer sequence outperformed the PNA sequence in isotonic saline buffer, while the opposite
15 was true for low salt conditions. Addition of 1 μ M displacer DNA to alkaline phosphatase immobilized through double-stranded biotinylated DNA was released completely into solution within seconds. The system was equally efficient when applied to the immuno-PCR assay. Displacement conditions using DNA were identical to prior wash conditions and compatible with PCR. Capture/displacement resulted in a clear
20 reduction in background without affecting signal.

Kinetics of Displacement: Alkaline Phosphatase was conjugated to a 15 base capture oligonucleotide (GTGCTTCCTC TTTCT (SEQ ID NO:8)) via a 5' amino (C12) linker arm using disuccidimidyl suberate. The DNA was hybridized to a complimentary 22 base anchor oligonucleotide (5'-GACACACAGA AAGAGGAAGC AC (SEQ ID
25 NO:9)) labeled with biotin through a 5' amino linker arm, resulting in alkaline phosphatase labeled with biotin through a partially double-stranded DNA linker. The alkaline phosphatase/DNA conjugate was dissolved in PBS containing 1 MM MgCl₂, 0.1 mM ZnCl₂, and 0.1% BSA. Fifty micrograms avidinylated paramagnetic

- 5 microparticles (BioMag Streptavidin, Polysciences, Inc., Warrington PA, 18976) were washed with the same buffer and combined with 2.5 µg alkaline phosphatase/DNA conjugate in 0.5 ml buffer. Approximately half of the enzyme activity was found bound to the microparticles as determined by monitoring the change in optical density at 405 nm in the presence of 1 mg/ml *para*-nitrophenyl phosphate dissolved in 2.4 M
- 10 diethanolamine, 57 µM MgCl₂, pH 10. The particles were washed 4 times in buffer and divided into three equal amounts. The release of enzyme activity from the microparticles into solution was monitored as a function of time following the addition of displacement oligonucleotide or protein nucleic acid (PNA) (5'-CTTCCTCTTTCTGTGTGT (DNA backbone: SEQ ID NO:6 and PNA backbone: SEQ ID NO: 11)).

15 **Table 1.**

	Time (min)	Soluble Enzyme Activity
Control (no addition)	5	1.3%
	10	1.4%
	20	1.4%
	30	1.5%
PNA addition	1	50%
	3	65%
	5	80%
	10	90%
	20	94%
	30	97%
DNA addition	1	82%
	3	91%
	5	97%
	10	98%
	20	98%
	30	98%

5 This observation was repeated several times using Alkaline Phosphatase conjugated to (5'-GCTACTTGAC TTCGAGTGCT TCCTCTTTCT (SEQ ID NO:5)) / (5'-biotin-GACACACAGA AAGAGGAAGC AC (SEQ ID NO:9)) and removed with the same displacer at 1 μ M. In all cases, almost 100% of the bound enzyme activity was displaced back into solution within 5 minutes.

10 Displacement kinetics can also be observed with antibody conjugates to PSA displaced back into solution. The presence of low amounts of antibody in solution is determined by ELISA. The antibody against PSA is captured onto PSA-coated plates, then coated with a secondary HRP-Ab. The HRP activity is proportional to the presence of the first antibody.

15 Microtiter plates coated with avidin (Reacti-Bind Neutravidin Coated Polystyrene Strip Plate with SuperBlock Blocking Buffer, Pierce, Rockford, IL 61105) were incubated for 30 minutes with 10 nM anti-PSA Ab (unlabeled, labeled with biotin directly, or conjugated to the capture/biotinylated anchor oligonucleotide hybrid). The wells were washed three times in PBS containing 0.05% Tween. The antibody conjugate
20 was displaced by the addition of 1 μ M displacer oligonucleotide and the corresponding PNA in 10 mM Tris, pH 8, containing 0 to 500 mM salt. The wells were drained and washed as a function of incubation time. Anti-mouse antibody labeled with HRP was added to the wells and incubated for 1.5 hours. Anti-PSA antibody was determined by HRP activity measured at 490 nm in the presence of OPD/peroxide in a Molecular
25 Devices Corp. plate reader. Note that although PNA is used in this example, DNA and RNA molecules may also be used as a displacer nucleic acid.

5 Figure 3 shows that the capture/anchor hybrid is stable under the salt conditions of the buffer. The antibody/biotinylated DNA conjugate remains bound to the well, as well as controls. Figure 4 shows the effect of PNA displacement on the bound antibody/biotinylated DNA conjugate. At low ionic strength, PNA displacement is very effective, removing the antibody within a few minutes. It is not as effective at high salt.

10 Figure 5 shows displacement with a molecule of DNA. It is very effective at high salt, and ineffective in the absence of salt.

Displacement/Recapture: If necessary, the capture/displacement concept could be extended to include another round of capture and release. To test this hypothesis, longer, 30 base capture sequence was synthesized, containing a second region

15 complimentary to a second capture sequence. Immune complex displaced into solution from the first avidin coated support would be recaptured by solution hybridization to a second biotinylated sequence, followed by exposure to a fresh avidin solid support. Each capture/release step improves sensitivity by removing nonspecific reporter MAb-DNA. The capture DNA sequence for the capture/displacement/recapture system was

20 conjugated to alkaline phosphatase and capture MAb. The system was analyzed for efficacy by following enzyme activity captured, displaced and recaptured onto paramagnetic particles. The MAb conjugate was then incorporated into the immuno-PCR assay. In preferred embodiments of the present invention, only one round of capture/displacement is being explored. For the instant invention, capture/displacement

25 is used. However, if required, a additional capture /displacement steps may be used in the instant invention.

5 **Table 2: Sequences for Capture/Displacement NADIA**

Anchor sequence for Biotinylation: (29mer)	(SEQ ID NO: 1)
5' NH ₂ - (C ₁₂) -GAGCTCGATC GTCCCAGTCT GAAGTCCTA 3'	
	9470 g/mole; e = 2.75E5; 1 od = 34.4 µg/ml or 3.64 µM
Capture sequence for antibody labeling (22 mer)	(SEQ ID NO:2)
5' NH ₂ - (C ₁₂) -TAGGACTTCA GACTGGGACG AT 3'	
	7261 g/mole; e = 2.18E5; 1 od = 33.2 µg/m or 4.58 µM
Displacer sequence (27 mer)	(SEQ ID NO:3)
5' GGACTTCAGA CTGGGACGAT CGAGCTC 3'	
	8897 g/mole; e = 2.60E5; 1 od = 34.2 µg/ml or 3.85 µM
1st capture	(SEQ ID NO:4)
3' CACGAAGGAG AAAGACACAC AG 5' - (C ₁₂) -NH ₃ -biotin	
	MW = 9574, e = 2.59E5, 1 OD = 37 µg/ml or 3.86 µM
30mer	(SEQ ID NO:5)
Capture Ab-5' NH ₃ -(C ₁₂)-GCTACTTGAC TTCGAGTGCT TCCTCTTTCT	
Removal PNA	(SEQ ID NO: 11)
5' CTCCTCTTT CTGTGTGT 3'	
2nd capture	
3' CGATGAACTG AAGCTCAC- (C ₁₂) -NH ₂ 5'-biotin	
or	
5' NH ₃ - (C ₁₂) -CACTCGAA GTCAAGTAGC	(SEQ ID NO:7)
	MW = 5782, e = 1.785E5, 1OD = 32.4 µg/ml or 5.6 µM

The invention illustratively described herein can suitably be practiced in the absence of any element or elements, limitation or limitations that are not specifically disclosed herein. Thus, for example, the terms "comprising," "including," "containing," etc. shall be read expansively and without limitation. Additionally, the terms and expressions employed herein have been used as terms of description and not of

10

5 limitation, and there is no intention in the use of such terms and expressions of excluding
any equivalent of the invention shown or portion thereof, but it is recognized that various
modifications are possible within the scope of the invention claimed. Thus, it should be
understood that although the present invention has been specifically disclosed by
preferred embodiments and optional features, modifications and variations of the
10 inventions embodied herein disclosed can be readily made by those skilled in the art, and
that such modifications and variations are considered to be within the scope of the
inventions disclosed herein. The inventions have been described broadly and generically
herein. Each of the narrower species and subgeneric groupings falling within the generic
disclosure also form the part of these inventions. This includes within the generic
15 description of each of the inventions a proviso or negative limitation that will allow
removing any subject matter from the genus, regardless or whether or not the material to
be removed was specifically recited. In addition, where features or aspects of an
invention are described in terms of the Markush group, those schooled in the art will
recognize that the invention is also thereby described in terms of any individual member
20 or subgroup of members of the Markush group. Further, when a reference to an aspect
of the invention lists a range of individual members, as for example, 'SEQ ID NO: 1 to
SEQ ID NO: 100, inclusive,' it is intended to be equivalent to listing every member of
the list individually, and additionally it should be understood that every individual
member may be excluded or included in the claim individually.

25 The steps depicted and/or used in methods herein may be performed in a different
order than as depicted and/or stated. The steps are merely exemplary of the order these
steps may occur. The steps may occur in any order that is desired such that it still
performs the goals of the claimed invention.

5 From the description of the invention herein, it is manifest that various
equivalents can be used to implement the concepts of the present invention without
departing from its scope. Moreover, while the invention has been described with specific
reference to certain embodiments, a person of ordinary skill in the art would recognize
that changes can be made in form and detail without departing from the spirit and the
10 scope of the invention. The described embodiments are considered in all respects as
illustrative and not restrictive. It should also be understood that the invention is not
limited to the particular embodiments described herein, but is capable of many
equivalents, rearrangements, modifications, and substitutions without departing from the
scope of the invention. Thus, additional embodiments are within the scope of the
15 invention and within the following claims.

Further, all patents and publications described herein are hereby incorporated by
reference to the same extent as if each individual patent or publication was specifically
and individually indicated to be incorporated by reference.

5

CLAIMS

What is claimed is:

1. A method for detecting a non-nucleic acid analyte present in a sample, the method comprising the steps of:
 - (i) contacting a sample comprising a non-nucleic acid analyte with a reporter conjugate, wherein the reporter conjugate comprises:
 - (a) a first receptor capable of specifically binding the analyte; and
 - (b) a nucleic acid marker;
 - (ii) allowing the binding of the analyte to the reporter conjugate, thereby forming an analyte-dependent reporter complex;
 - 15 (iii) contacting the analyte-dependent reporter complex with a second receptor for the analyte, wherein the second receptor is attached to a solid support via a nucleic acid bridge of predetermined sequence;
 - (iv) allowing the binding of the second reporter to the analyte-dependent reporter complex, thereby forming an analyte-dependent reporter/second reporter complex attached to the solid support;
 - 20 (v) eluting the analyte-dependent reporter/second receptor complex from the solid support with a displacer nucleic acid; and
 - (vi) specifically detecting the presence of the nucleic acid marker in the eluted analyte-dependent reporter/second receptor complex, wherein the
25 detection of nucleic acid marker indicates the presence of the analyte in the sample.

- 5 2. The method of claim 1, wherein detecting the presence of the nucleic acid marker comprises:
- (i) contacting the eluted analyte-dependent reporter/second receptor complex with a nucleic acid replication composition capable of replicating the nucleic acid marker sequence,
- 10 (ii) replicating the nucleic acid marker; and
- (iii) visualizing the replicated nucleic acid marker by ethidium bromide staining.
3. The method of claim 2, wherein the nucleic acid marker is replicated with a polymerase.
- 15 4. The method of claim 3, wherein the polymerase is selected from the group consisting of a DNA polymerase, a RNA polymerase, a transcriptase, and a Q-beta polymerase.
5. The method of claim 2, wherein the replication composition comprises reagents and primers for conducting a polymerase chain reaction, and wherein replicating
- 20 the nucleic acid marker comprises amplifying the nucleic acid marker by the polymerase chain reaction.
6. The method of claim 1, wherein the first and second receptors are antibodies and the non-nucleic acid analyte is an antigen or a hapten.
7. The method of claim 5, wherein the polymerase chain reaction is a real-time
- 25 polymerase chain reaction.
8. The method of claim 1, wherein the analyte is PSA.

- 5 9. The method of claim 1, wherein the sample is a serum sample and the analyte is present at a concentration of less than 10 picograms per milliliter.
10. The method of claim 1, further comprising the step of washing the analyte-dependent reporter/second receptor complex attached to the solid support formed in step (iv) prior to eluting the analyte-dependent reporter/second receptor
- 10 complex from the solid support with a displacer nucleic acid in step (v).
11. A method for simultaneously detecting a multiplicity of different non-nucleic acid analytes present in a single sample, the method comprising the steps of:
- (i) contacting a sample comprising a multiplicity of different non-nucleic acid analytes with a multiplicity of reporter conjugates, wherein each
- 15 reporter conjugate comprises:
- (a) a first receptor capable of specifically binding one of the multiplicity of non-nucleic acid analytes in the sample; and
- (b) a nucleic acid marker, wherein each reporter conjugate binds specifically to a different analyte and comprises a nucleic acid that
- 20 is distinguishable from the other nucleic acids in the multiplicity of reporter conjugates;
- (ii) allowing the binding of the multiplicity of non-nucleic acid analytes in the sample to the multiplicity of receptor conjugates, thereby forming a multiplicity of analyte-dependent reporter complexes;
- 25 (iii) contacting the multiplicity of analyte-dependent reporter complexes with a multiplicity of second receptors, wherein the multiplicity of second receptors is collectively capable of binding to the multiplicity of analytes

- 5 in the sample, and wherein the second receptors are attached to a solid support via a nucleic acid bridge of predetermined sequence;
- (iv) allowing the binding of the second reporters to the analyte-dependent reporter complexes, thereby forming a multiplicity of analyte-dependent reporter/second reporter complexes attached to the solid support;
- 10 (v) eluting the multiplicity of analyte-dependent reporter/second receptor complexes from the solid support with at least one displacer nucleic acid; and
- (vi) specifically detecting the presence of the nucleic acid markers in the eluted multiplicity of analyte-dependent reporter/second receptor
- 15 complexes by visualizing the replicated nucleic acid marker by ethidium bromide staining, wherein the detection of each distinguishable nucleic acid marker indicates the presence of the corresponding analyte in the sample.

12. The method of claim 11, wherein detecting the presence the nucleic acid markers
- 20 comprises:
- (i) contacting the eluted multiplicity of analyte-dependent reporter/second receptor complexes with a nucleic acid replication composition capable of replicating the nucleic acid markers;
- (ii) simultaneously replicating all of the distinguishable nucleic acid markers;
- 25 and
- (iii) visualizing the replicated nucleic acid markers by ethidium bromide staining.

- 5 13. The method of claim 12, wherein the nucleic acid markers are replicated with a polymerase.
14. The method of claim 13 wherein the polymerase is selected from the group consisting of a DNA polymerase, a RNA polymerase, a transcriptase, and a Q-beta polymerase.
- 10 15. The method of claim 12, wherein the nucleic acid replication composition comprises reagents and primers for conducting a polymerase chain reaction, and wherein replicating the nucleic acid markers comprises amplifying the nucleic acid markers in a polymerase chain reaction.
- 15 16. The method of claim 11, wherein the multiplicity of first and second receptors are antibodies and the multiplicity of non-nucleic acid analytes comprise antigens, haptens or a combination thereof.
17. The method of claim 15, wherein the polymerase chain reaction is a real-time polymerase chain reaction.
18. The method of claim 11, wherein one of the multiplicity of non-nucleic acid analytes is PSA.
- 20 19. The method of claim 11, wherein the sample is a serum sample and at least one of the multiplicity of non-nucleic acid analytes is present at a concentration of less than 10 picograms per milliliter.
20. A method for reversibly binding an antibody/analyte complex to a solid support, the method comprising the steps of:
- 25 (iv) providing an antibody/analyte complex, wherein the 5' end of a first nucleic acid is conjugated to the antibody, the analyte comprises an

- 5 antigen recognized by the antibody, and the analyte is specifically bound to the antibody through the antigen combining site of the antibody;
- (v) providing a solid support comprising a second nucleic acid, wherein the 5' end of the second nucleic acid is bound to the solid support, wherein the second nucleic acid is substantially complementary to the first nucleic acid over its 3' terminus;
- 10 (vi) binding the antibody/analyte complex to the solid support by means of a double-stranded nucleic acid bridge, wherein the nucleic acid bridge is formed by hybridization of the unbound ends of the first and second nucleic acids; and
- 15 (vii) eluting the antibody/analyte complex from the solid support by means of a displacer nucleic acid.
21. A method for eluting a non-nucleic acid molecule that is attached to a solid support by means of a nucleic acid bridge, the method comprising the step of eluting the attached non-nucleic acid molecule by contacting the nucleic acid bridge with a displacer nucleic acid molecule under conditions that favor displacement of the nucleic acid bridge with the displacer nucleic acid.
- 20
22. A method for detecting a non-nucleic acid analyte present in a sample, the method comprising the steps of:
- (i) contacting a sample comprising a non-nucleic acid analyte with a reporter conjugate, wherein the reporter conjugate comprises:
- 25 (a) a first receptor capable of specifically binding the analyte; and
- (b) a nucleic acid marker;

- 5 (ii) allowing the binding of the analyte to the reporter conjugate, thereby forming an analyte-dependent reporter complex;
- (iii) contacting the analyte-dependent reporter complex with a second receptor for the analyte, wherein the second receptor is attached to a solid support via a nucleic acid bridge of predetermined sequence;
- 10 (iv) allowing the binding of the second reporter to the analyte-dependent reporter complex, thereby forming an analyte-dependent reporter/second reporter complex attached to the solid support;
- (v) eluting the analyte-dependent reporter/second receptor complex from the solid support with a displacer nucleic acid; and
- 15 (vi) specifically detecting the presence of the nucleic acid marker in the eluted analyte-dependent reporter/second receptor complex, wherein the detection of nucleic acid marker indicates the presence of the analyte in the sample.
23. A method for detecting a non-nucleic acid analyte in a sample comprising the
- 20 steps of
- (i) contacting a sample comprising a non-nucleic acid analyte with a conjugate, wherein the conjugate comprises:
- (a) a receptor capable of specifically binding the analyte, and
- (b) a nucleic acid marker;
- 25 (ii) allowing the binding of the analyte and the conjugate comprising the receptor thereby forming an analyte-dependent reporter complex;

- 5 (iii) contacting the analyte-dependent reporter complex with a second receptor for the analyte wherein the second receptor is attached to a solid support via a nucleic acid bridge of predetermined sequence;
- (iv) eluting the analyte-dependent reporter/second receptor complex with a means for eluting the complex from the solid support; and
- 10 (v) specifically detecting the presence of the nucleic acid marker in the eluted analyte-dependent reporter/second receptor complex, wherein the detection of the nucleic acid marker indicates the presence of the analyte in the sample.
24. The method of claim 23, wherein the means for means for eluting the complex from the solid support is an endonuclease.
- 15 25. A kit for detecting a non-nucleic acid analyte comprising:
- (i) a first container comprising a first receptor capable of specifically binding to an analyte and a negative control receptor;
- (ii) a second container containing a second receptor for the analyte; wherein
- 20 the second receptor is attached to a solid support via a nucleic acid bridge.
26. A method for detecting a non-nucleic acid analyte present in a sample, the method comprising the steps of:
- (i) contacting a sample comprising a non-nucleic acid analyte present in a sample to a solid support by a linker comprising a nucleic acid bridge;
- 25 (ii) releasing the non-nucleic acid analyte from the solid support by a means for releasing the non-nucleic acid analyte; and

- 5 (iii) measuring the released non-nucleic acid analyte, thereby detecting the non-nucleic acid analyte.

27. A kit for detecting a non-nucleic acid analyte comprising:

- 10 (i) a first container comprising activated DNA molecules for labeling a receptor, wherein the receptor is capable of specifically binding the non-nucleic acid analyte, wherein the activated DNA molecules comprises at least one of:
- (a) a first strand of a nucleic acid bridge, and
- (b) a first strand of a marker DNA molecule;
- (ii) a second container comprising complimentary DNA molecules, wherein
- 15 the complementary DNA molecules comprise:
- (a) DNA molecules conjugated to a ligand, wherein the DNA molecules are substantially complementary to the first strand of the nucleic acid bridge,
- (b) DNA molecules substantially complementary to the first strand of
- 20 the marker DNA molecule, and
- (c) displacer strand DNA molecules; and
- (iii) directions for detecting a non-nucleic acid analyte using the kit.
28. The kit according to claim 28, wherein the activated DNA molecules are activated with disuccinimidyl suberate.
- 25 29. The kit according to claim 29, wherein the activated DNA molecules are activated with maleimidobenzoyl-N-hydroxysuccinimide ester (MBS).

- 5 30. The kit according to claim 28, wherein the ligand is biotin.
31. A kit for labeling proteins, polypeptides or peptides comprising:
- (i) a container comprising DNA molecules activated with disuccinimidyl
 suberate, wherein the DNA molecules are selected from the group
 consisting of: *
- 10 (a) a first strand of a nucleic acid bridge, and
- (b) a first strand of a marker DNA molecule; and
- (ii) directions for labeling proteins, polypeptides or peptides using the kit.

Figure 1

1/2

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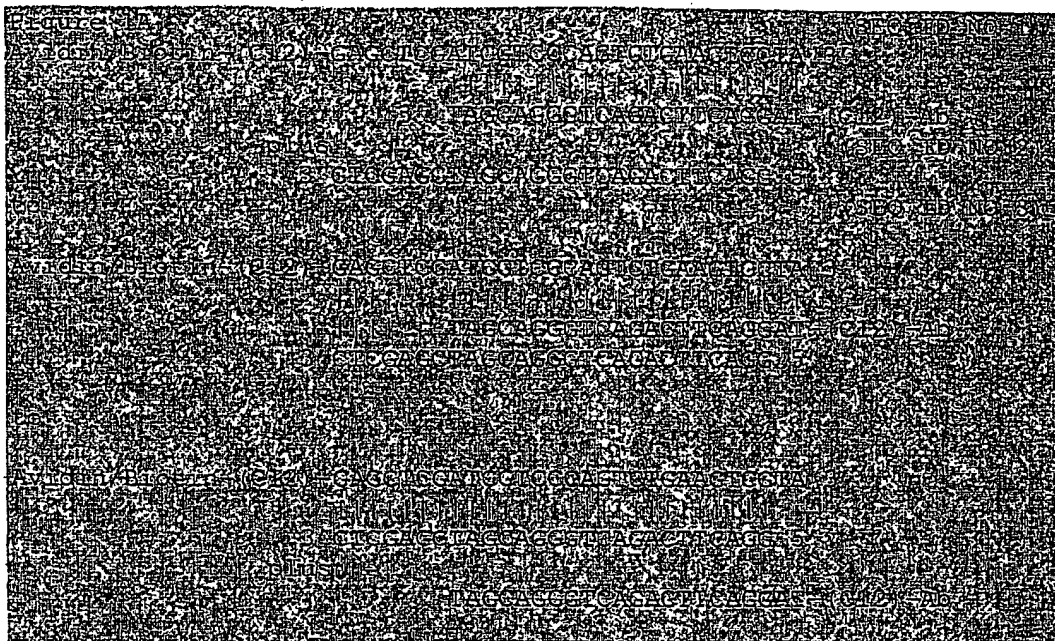


Figure 1

2/2

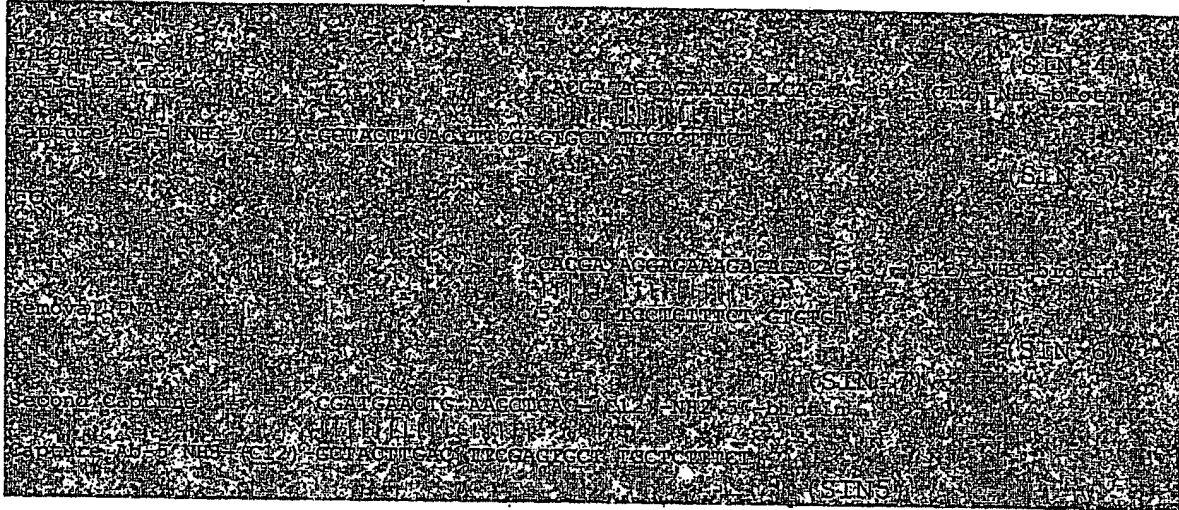


Figure 2

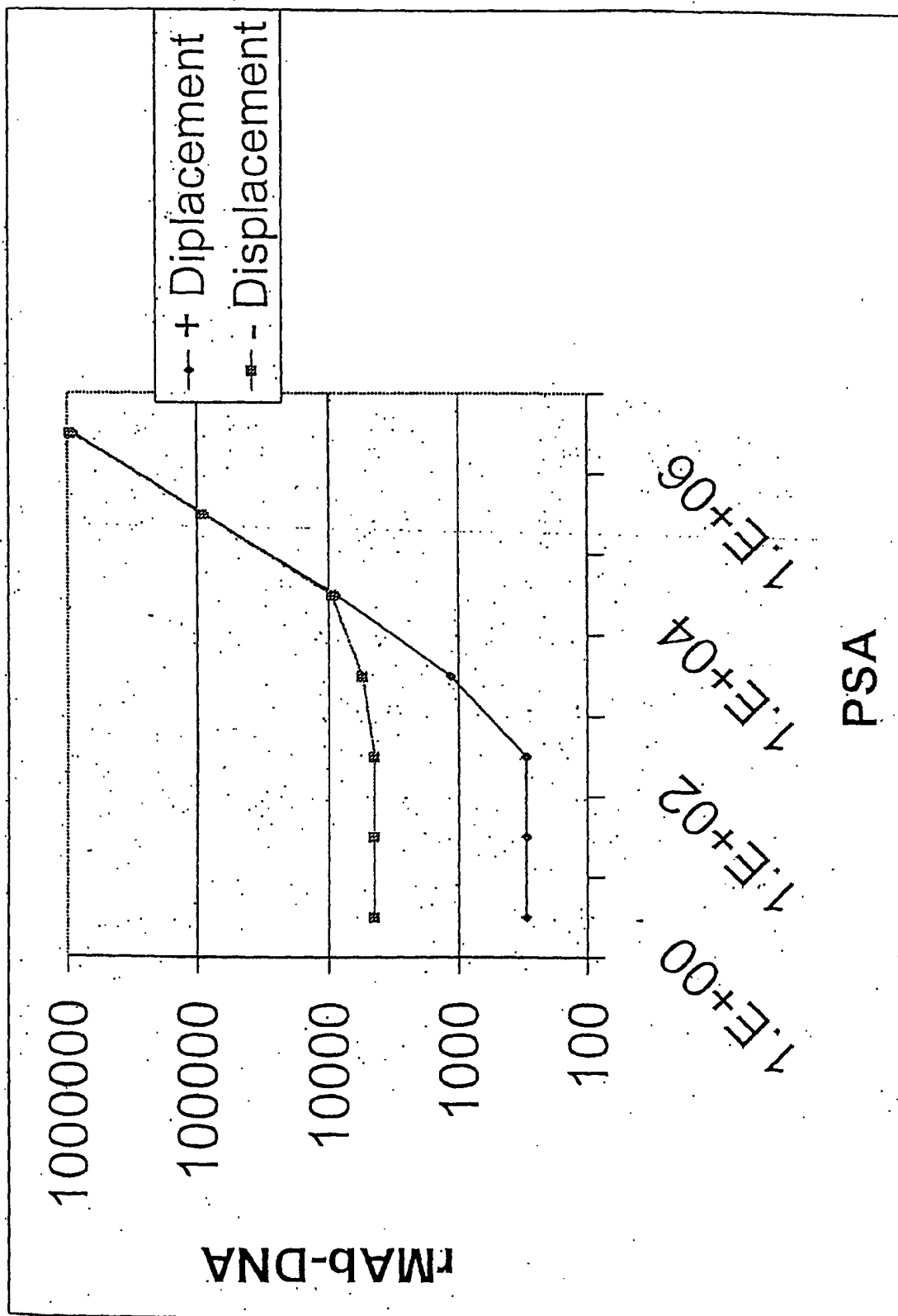


Figure 3

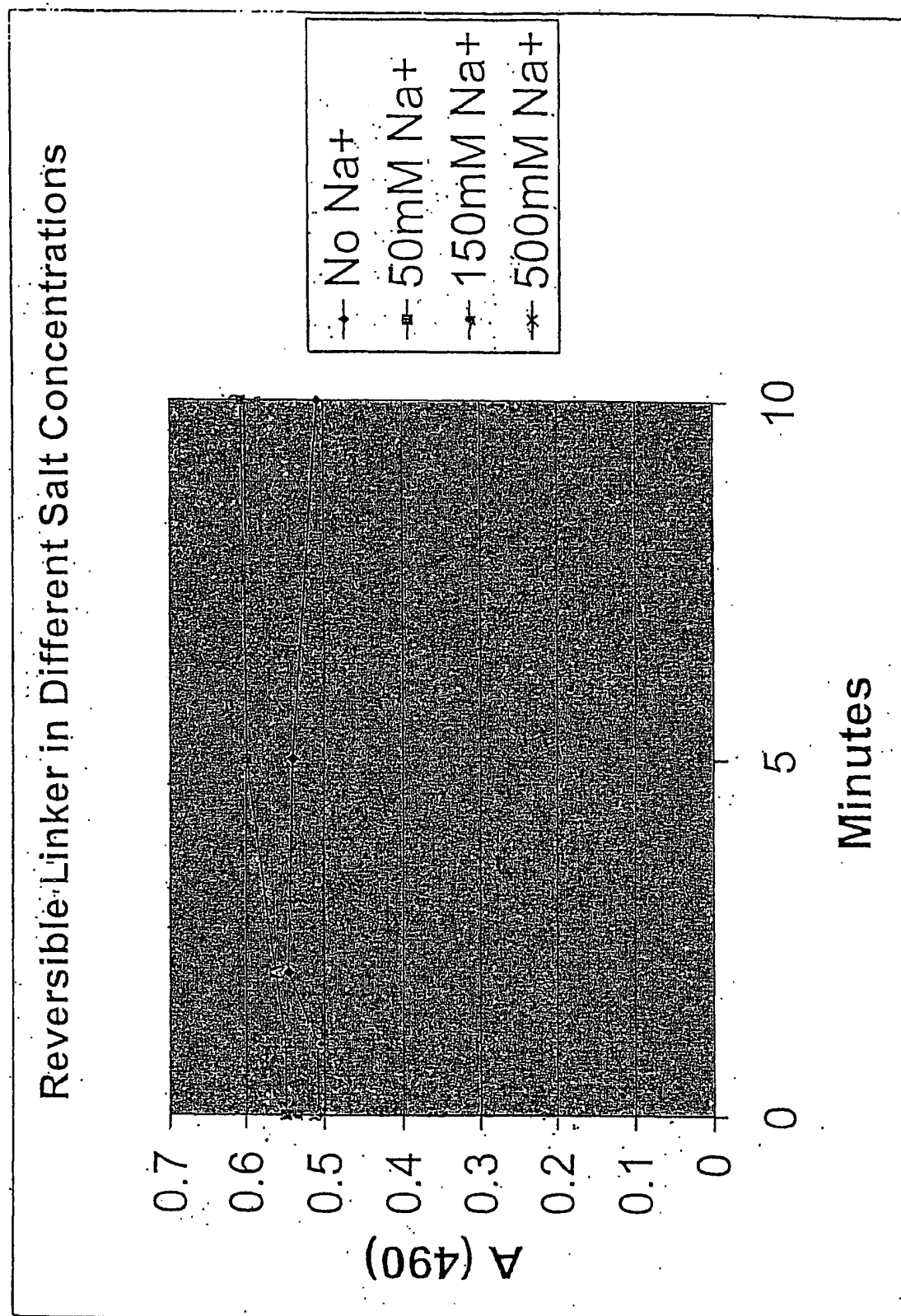


Figure 4

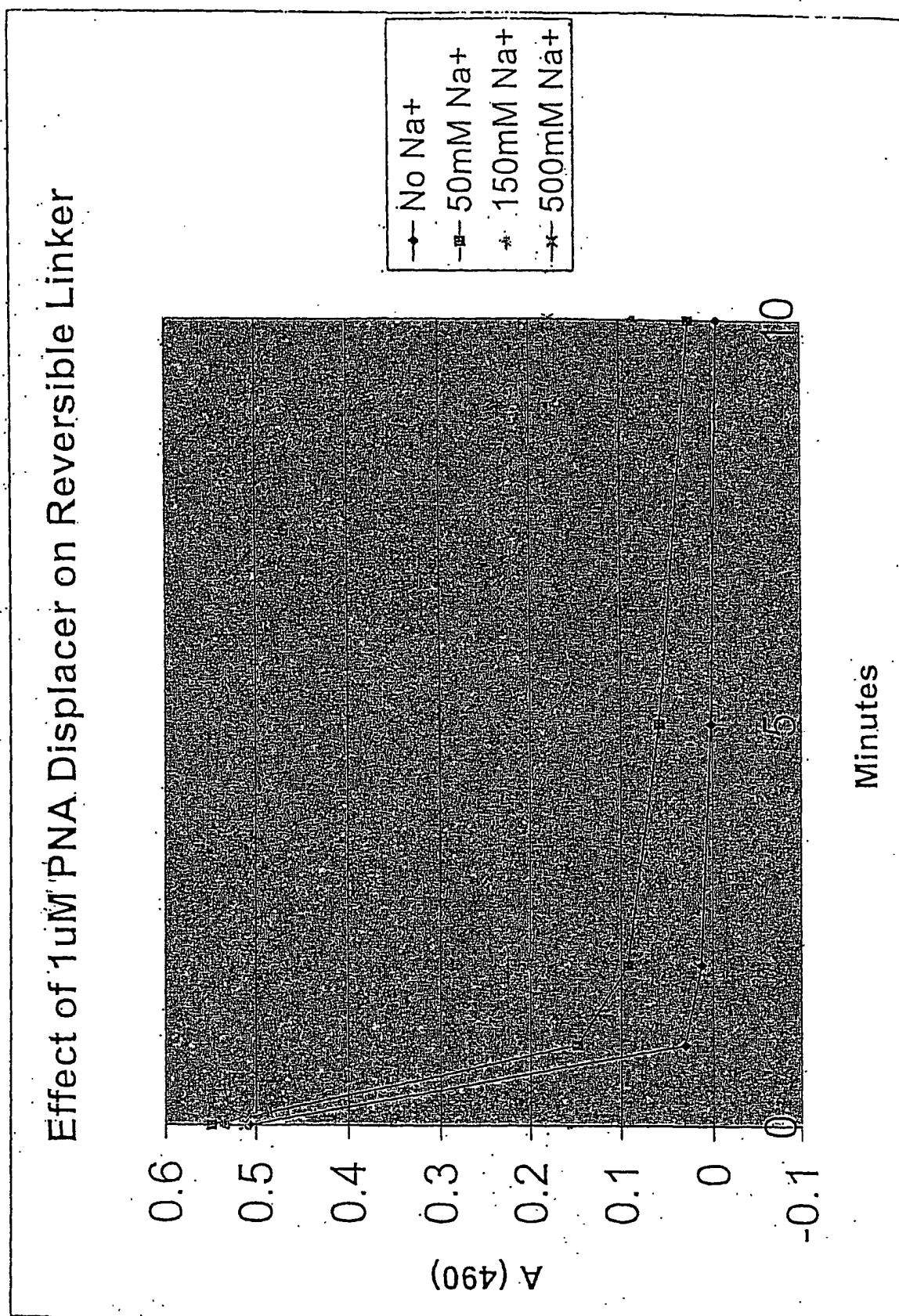


Figure 5

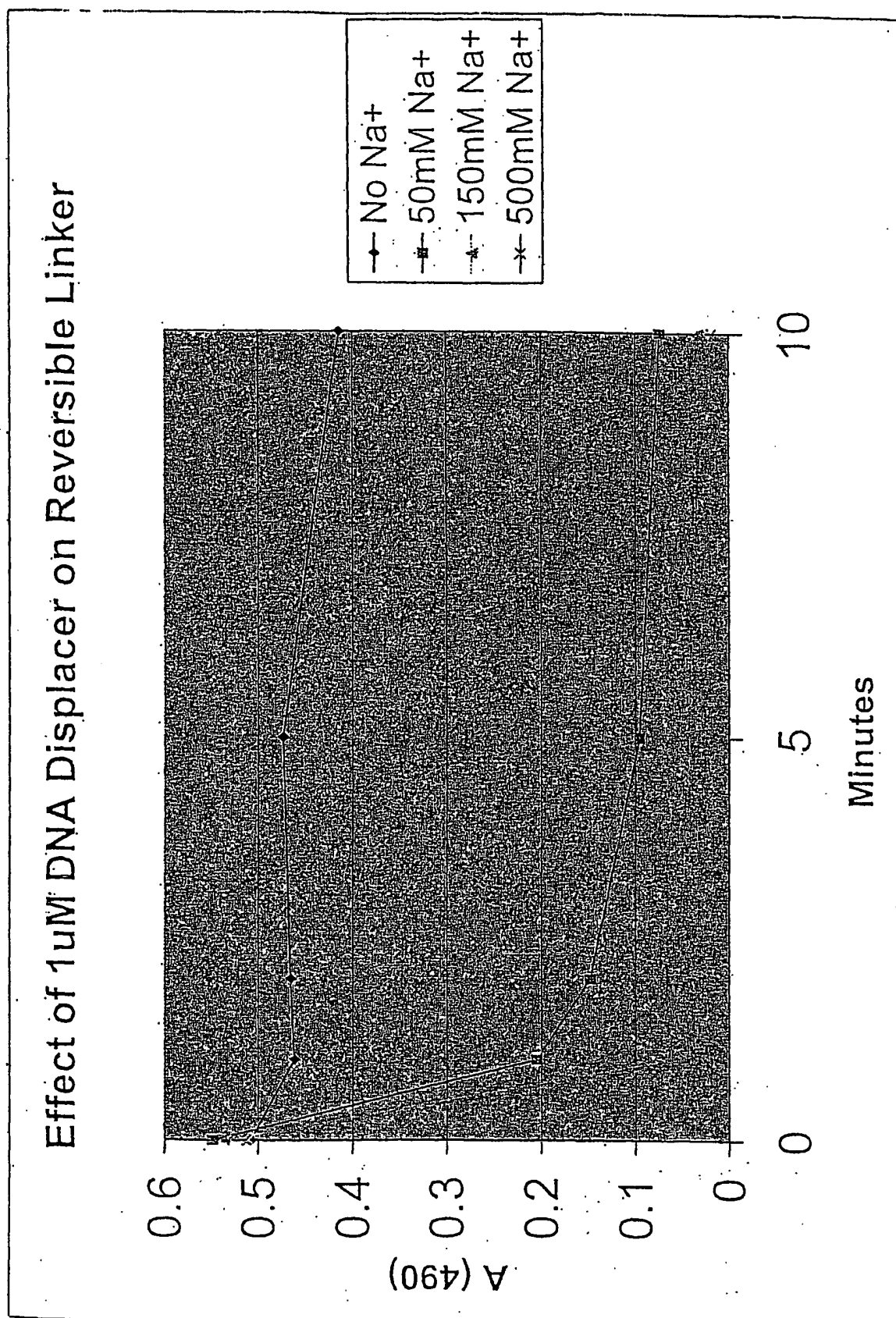
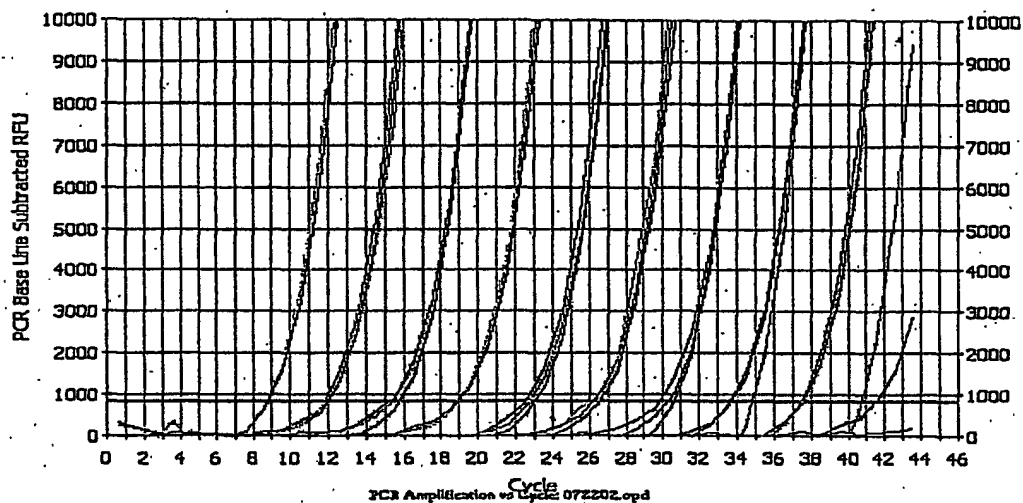


Figure 6

A) Real-time fluorescence signal obtained from a standard dilution series of anti-PSA rMAb-DNA conjugate.



B) The threshold cycle as a function of the initial number of rMAb-DNA molecules from (A)

Correlation Coefficient: 0.999 Slope: -3.647 Intercept: 38.067 $Y = -3.647 X + 38.067$
PCR Efficiency: 88.0 %

□ Unknowns
● Standards

